

# NASA METROLOGY AND CALIBRATION 1993

*Proceedings of the Sixteenth  
Annual Workshop  
April 20-22, 1993*



**National Aeronautics and  
Space Administration**

**NIST**

**National Institute of Standards  
and Technology**

**JPL**

**Jet Propulsion Laboratory  
Pasadena, California 91109**



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-Archie Miiller and Charles Tilford

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**Stennis Space Center - Herman Watts**

**Wallops Flight Facility - Robert Nock**

**White Sands Test Facility - Troy Estes**

### **EXTRANEEOUS MATERIAL**



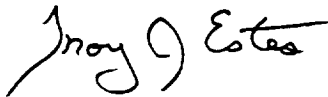
## INTRODUCTION

NASA's Office of Safety and Mission Quality sponsors the Metrology and Calibration Working Group. The Working Group

- Provides Agencywide standardization of individual metrology programs, where appropriate
- Promotes cooperation and exchange of information within NASA, with other Government agencies, and with industry
- Serves as the primary Agency interface with the National Institute of Standards and Technology
- Encourages formal quality control techniques such as Measurement Assurance Programs

An annual workshop is the primary vehicle for achieving these goals. The sixteenth annual workshop was cohosted by the National Institute of Standards and Technology in Rockville, Maryland, April 20-22, 1993.

These proceedings contain unedited reports and presentations from the 1993 workshop and are provided for information only. The use of trade names in this publication does not constitute an endorsement, either expressed or implied, by the National Aeronautics and Space Administration.



Troy J. Estes  
Chairman, NASA Metrology and Calibration Working Group



**WORKSHOP AGENDA  
AND  
ATTENDEES LIST**



**16TH ANNUAL NASA METROLOGY AND CALIBRATION WORKSHOP  
AGENDA  
(UPDATED)**

**MONDAY - APRIL 19**

- 1:30 NIST Informal Technical Discussions (By prior arrangement)  
5:00 Pre-conference Reception at the Potomac Inn (Polo Lounge)

**TUESDAY - APRIL 20**

- |      |                             |   |
|------|-----------------------------|---|
| 8:00 | Opening Announcements       | S. Bednarczyk , JPL<br>Dr. N. Belecki, NIST |
| 8:05 | Welcome to NIST             | R. Kammer, NIST Director                    |
| 8:20 | NASA Code QR Overview       | C. Schnieder, NASA HQ                       |
| 8:35 | Opening Remarks             | R. Burdine, NASA HQ                         |
| 8:50 | Workshop Goals & Objectives | T. Estes, W/G Chair                         |

**GUEST PRESENTATIONS**

- |      |                                       |   |
|------|---------------------------------------|---|
| 9:00 | DOE Metrology Program                 | Dr. R. Johnson, Sandia Lab                      |
| 9:20 | Process Measurement Assurance Program | J. Everhart, EG&G Mound<br>Applied Technologies |

**10:00 MORNING BREAK**

**NIST PAPERS**

- |       |   |                         |
|-------|---|-------------------------|
| 10:15 | Challenges to the NIST Electromagnetic Measurements Program                 | Dr. R. E. Hebner, NIST  |
| 10:45 | Research into Measurement of Flow, Temperature, Humidity & Transient Press. | Dr. G. J. Rosasco, NIST |
| 11:15 | New Developments at NIST in Vacuum, Low Pressure and Leak Rate Standards    | Dr. C. Tilford, NIST    |
| 11:45 | Challenges in Dimensional Metrology at NIST                                 | Dr. D. Swyt , NIST      |

**12:15 LUNCH BREAK**

- |      |  |                        |
|------|--|------------------------|
| 1:30 | Optical & Infrared Radiation Measurements Program at NIST              | Dr. A. C. Parr, NIST   |
| 2:00 | Ultraviolet Radiation Measurements at NIST                             | Dr. R. P. Madden, NIST |
| 2:30 | Cost Effective Calibration through Formal Test Optimization Techniques | T. Souders, NIST       |

**3:00 AFTERNOON BREAK**

## 16TH ANNUAL NASA METROLOGY AND CALIBRATION WORKSHOP AGENDA

**TUESDAY - APRIL 20 (Continued)**

3:15	Mobile Calibration System for Electrical Instrumentation.	D. Kuchta, LaRC/Wyle Labs
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**WORKING GROUP PLENARY SESSION**

3:30	Working Group Procedures Election of Working Group Officers 1994 Workshop Site Selection	T. Estes, W/G Chair
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4:35 MWG Budget Process discussion R. Burdine, NASA HQ

**4:45 ADJOURN**

**8:00 NASA MWG REPRESENTATIVES  
EXECUTIVE SESSION  
(Hospitality Suite)** R. Burdine, NASA HQ

**WEDNESDAY - APRIL 21**

8:00	Announcements	T. Estes/S. Bednarczyk/ Dr. N. Belecki
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## TECHNICAL PRESENTATIONS

8:05 Center-line Adjustment Update K. Schaaf, WSTF/Lockheed

## SPACE BASED METROLOGY

8:15	Space Based Metrology Committee Report	M. Hutchinson, SBMC Chair
8:30	SSF Metrology - The WP01 Approach	R. Humphries, Jr., MSFC
9:00	SSF Metrology Locker	R. Smith, JSC/Simco

**9:20 MORNING BREAK**

9:35	Systems Approach to SBM	R. Martin, JPL
10:35	Statistical Process Measurement Control	Dr. H. Castrup, ISG

**12:10 LUNCH BREAK**

## NIST TOUR

1:30 NIST Tour (See attached schedule for details)  
4:30 Return from Tour  
6:00 **Banquet @ Claudes- 9021 Gaither Rd, Gaithersburg ( Norm Belecki, NIST)**



# 16TH ANNUAL NASA METROLOGY AND CALIBRATION WORKSHOP AGENDA

## THURSDAY - APRIL 22

8:00 Announcements

T. Estes/S. Bednarczyk  
Dr. N. Belecki

### MAP Reports

8:05 Accelerometer MAP

M. Cerezo, JPL

8:15 Voltage MAP

K. Riley, KSC

8:25 Temperature MAP

T. Sappington, SSC/Sverdrup

8:35 Microwave MAP

T. Estes, WSTF

8:45 Fiber-optic MAP

W. McPeters, JSC/Simco

8:55 Resistance MAP

M. Hutchinson, LaRC

### RTOP REPORTS

9:05 Low Pressure Transfer Standard

A. Miller, NIST

9:20 Leak Artifact Calibration

A. Miller, KSC/EG&G

9:35 **MORNING BREAK**

9:50 Metrology Publication Report

R. Martin, JPL

10:05 MAP Publication

J. Riley, KSC

### RTOP PROPOSALS

10:20 Transient Pressure Standard

T. Estes, WSTF

10:35 Volt MAP Upgrade/Port. Josephson  
Junction Voltage Reference

K. Riley, KSC

10:50 Acceleration MAP Expansion

M. Cerezo, JPL

11:05 Capacitance MAP

W. McPeters JSC/Simco

11:20 Flight Voltage Reference

S. Bednarczyk, JPL

11:35 MASS Map

J. Riley, KSC

11:50 Josephson Junction

W. McPeters JSC/Simco

12:05 **LUNCH BREAK**

1:25 Working Group Plenary Session  
Research Program Discussion

T. Estes, W/G Chair

2:40 **AFTERNOON BREAK**

2:55 Space Based Metrology Issues

M. Hutchinson, SBMC Chair

4:10 **ADJOURNMENT OF WORKSHOP**

7:00 Space Based Metrology Committee Meeting (Hospitality Suite)



# 16TH ANNUAL METROLOGY AND CALIBRATION WORKSHOP

APRIL 20-22, 1993

## ATTENDEE LIST

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**ABBREVIATIONS:**

**ARC- Ames Research Center**

**DFRF- Dryden Flight Research Center**

**GSFC- Goddard Space Flight Center**

**JSC- Johnson Space Center**

**JPL- Jet Propulsion Laboratory**

**KSC- Kennedy Space Center**

**LaRC- Langley Research Center**

**LeRC- Lewis Research Center**

**MSFC- Marshall Space Flight Center**

**NIST- National Institute of Standards  
& Technology**

**SSC- Stennis Space Center**

**WFF- Wallops Flight Facility**

**WSTF- White Sands Test Facility**

# WORKSHOP OBJECTIVES





## WORKSHOP OBJECTIVES

The objectives of the workshop were to

- Exchange the latest metrology advances and techniques
- Develop an approach for supporting space-based metrology
- Finalize the Working Group operating procedures
- Establish a comprehensive, integrated research program

To meet these objectives, the Workshop agenda included

- Technical presentations by invited guests and metrology contractors
- Reports and discussions on space-based metrology
- Plenary sessions for discussing Working Group infrastructure
- Status reports on current research, proposals for new research, and integration of all research into a phased research program

Center reports were not presented but are included in the proceedings.





# **Metrology and Calibration Workshop**

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## **Goals and Objectives**

- Exchange latest metrology advances and techniques
- Develop approach for supporting space-based metrology
- Finalize Working Group operating procedures
- Establish comprehensive, integrated research program



## **Metrology and Calibration Workshop**

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# **Research Program Development**

- **Review Current Research**

- Objective
- Approach
- Customers
- Status

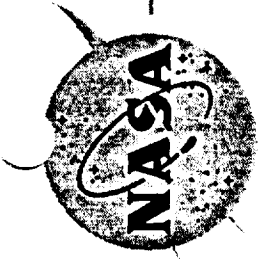
- **Propose New Research**

- Objective
- Approach
- Customers
- Benefits
- Funding Required

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# **Metrology and Calibration Workshop**

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## **Research Program Development**

- **Discuss Research**
  - Current
  - Proposed
  
- **Define Research Program**
  - Content
  - Priority
  - Schedule



# **Metrology and Calibration Workshop**

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## **Research Criteria**

- Sound objective and approach
- Well-defined, clear, and realistic benefit
- Agency-wide usefulness
- Programmatic application



# **Metrology and Calibration Workshop**

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## **Research Considerations**

**Is the cost of research reasonable?**

**Is the cost appropriate for the benefit expected?**

**Are there programmatic customers? Are there co-sponsors?**

**When should the research be funded for maximum benefit to the Agency?**





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**16th ANNUAL NASA METROLOGY AND CALIBRATION WORKSHOP**

# **OVERVIEW**

**APRIL 20, 1993**

**CARL SCHNEIDER  
DIRECTOR, QUALITY ASSURANCE  
NASA HEADQUARTERS**

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## **OUTLINE**

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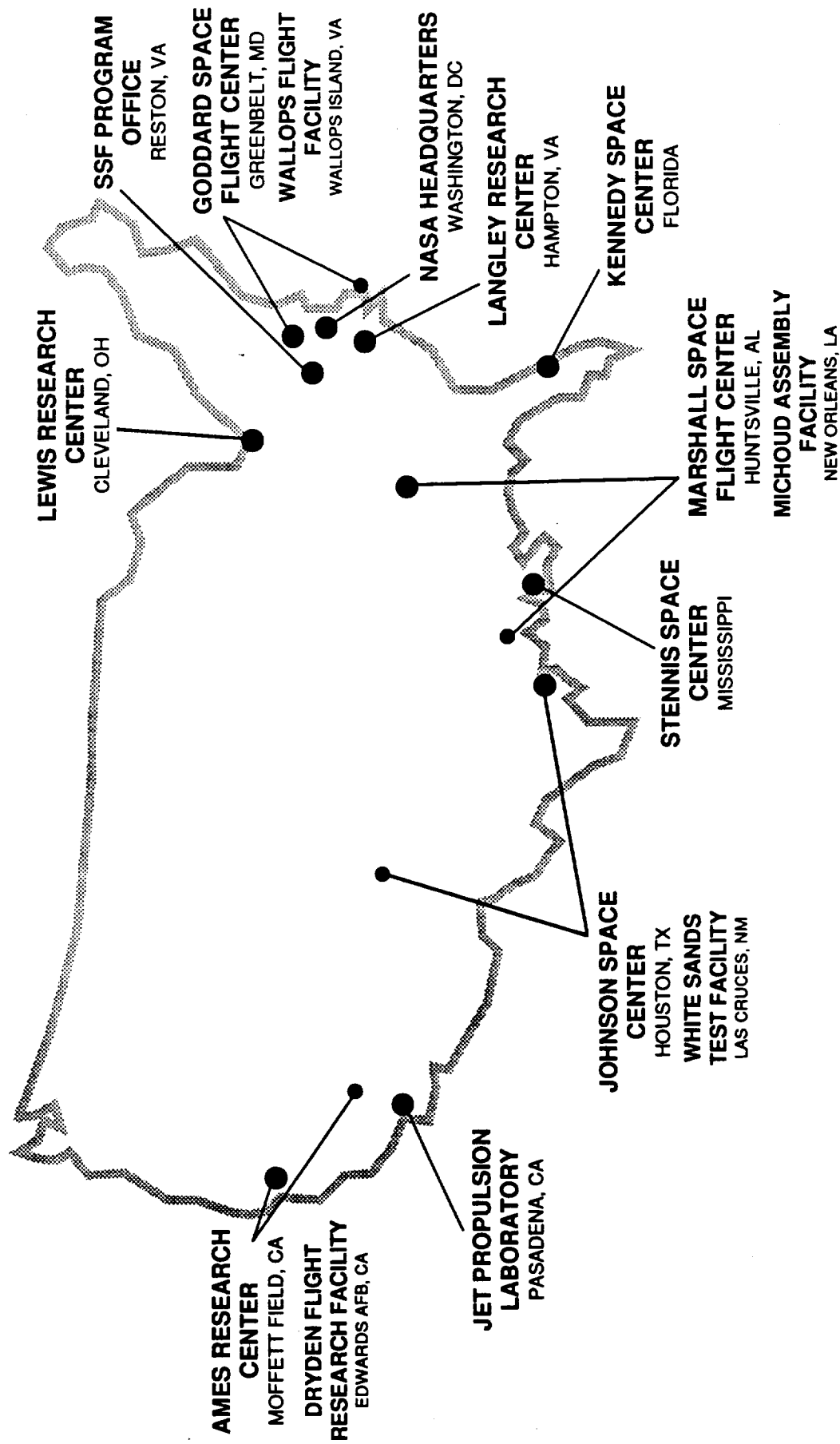
- **BACKGROUND**
- **ENVIRONMENT**
- **ORGANIZATIONAL REALIGNMENT**
- **DIRECTIONS FOR THE FUTURE**

## **BACKGROUND**

---

- **PRE-CHALLENGER**
  - SAFETY, RELIABILITY AND QUALITY ASSURANCE (SR&QA) DIVISIONS WITHIN OFFICE OF CHIEF ENGINEER (CODE D)
  - NASA SR&QA POLICIES WERE DECENTRALIZED AND DETERMINED BY EACH NASA FIELD CENTER
- **POST-CHALLENGER**
  - ROGER'S COMMISSION RECOMMENDATIONS
  - CODE Q CREATED, HEADED BY AN ASSOCIATE ADMINISTRATOR
  - DIRECT ACCESS BY SR&QA TO NASA ADMINISTRATOR
  - SR&QA POLICIES CENTRALIZED AT HEADQUARTERS

# NASA CENTERS AND FACILITIES



## **ENVIRONMENT**

---

- **NASA**
  - **ADVENTUROUS R&D ORGANIZATION TO A MATURING GOVERNMENT AGENCY**
  - **TECHNOLOGY DEVELOPMENT TO SPACE SYSTEMS OPERATIONS**
  - **UNLIMITED / LIMITED TO DECLINING BUDGET**
  - **FOCUS ON FEWER MORE EXPENSIVE SPACECRAFT**
  - **INCREASING INTERNATIONAL COOPERATION**
  - **CHANGE ORIENTED NASA ADMINISTRATOR**
  - **BLUE TEAM / RED TEAM ASSESSMENTS**
  - **"FASTER, BETTER, AND CHEAPER"**

## **ENVIRONMENT**

---

- **CODE Q**
  - **SIGNIFICANT BUDGET AUTHORITY**
  - **FOCUS ON INDEPENDENT ASSESSMENTS**
  - **ACTIVE AND INTEGRAL ROLE IN SPACE SHUTTLE LAUNCH PROCESS**
  - **INTENSE SR&QA SURVEYS OF ALL NASA CENTERS**
  - **CAS AS UNLIMITED RESOURCE**
  - **QA INVOLVED LATE IN PROGRAM LIFE CYCLE**
  - **CHANGE ORIENTED ASSOCIATE ADMINISTRATOR**

## **ORGANIZATIONAL REALIGNMENT**

---

- **REFOCUS ACTIVITIES EARLY IN PROGRAM LIFE CYCLE**
- **MAINTAIN BALANCE BETWEEN OVERSIGHT AND SUPPORT**
- **DEVELOP AN INTEGRATED RISK MANAGEMENT PROGRAM**
- **DEVELOP METRICS TO ASSESS EFFECTIVENESS**
- **CONSOLIDATE DISJOINTED CODE Q PROGRAMS**
- **REORGANIZE CODE Q**
- **NEW FOCUS ON SUPPLIER ASSURANCE AND CAS**

## **DIRECTIONS FOR THE FUTURE**

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- **QUALITY OF DESIGN AND PROCESS CONTROLS**
- **INCREASED COMPATIBILITY WITH DoD SYSTEMS**
- **INCREASED COMPATIBILITY WITH INTERNATIONAL PARTNERS**
- **QUANTITATIVE "VALUE ADDED" APPROACH TO QUALITY ASSURANCE AND RISK MANAGEMENT**
- **READILY ADAPTABLE TO CHANGE**
- **FASTER, BETTER, CHEAPER**



# **NASA METROLOGY WORKING GROUP CHALLENGES**

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- **FOSTER THE INTERACTION OF ALL NASA METROLOGY  
LABORATORIES AND FACILITIES**
- **ENCOURAGE EFFECTIVE CUSTOMER USE OF  
CALIBRATION SERVICES**
- **FACILITATE THE DEVELOPMENT AND RAPID  
REALIZATION OF MEASUREMENT TECHNOLOGIES**
- **PROMOTE CUSTOMER INTERACTION IN THE  
METROLOGY PROCESS**

## **NASA METROLOGY WORKING GROUP STRATEGIC THRUSTS**

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- **ESTABLISH / IMPLEMENT AN INTEGRATED NASA  
METROLOGY AND CALIBRATION PROGRAM**
- **PROVIDE THE BASIS FOR AGENCYWIDE  
MEASUREMENT ASSURANCE**
- **FACILITATE RESEARCH THAT PROMOTES NASA  
INTERESTS**

**INVITED SPEAKER  
PRESENTATIONS**



# **DOE METROLOGY PROGRAM PRESENTATION**

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## **NASA Metrology and Calibration Workshop**

**April 20, 1993**

**Ralph T. Johnson  
Sandia National Laboratories**



**Sandia National Laboratories**

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## **OUTLINE**

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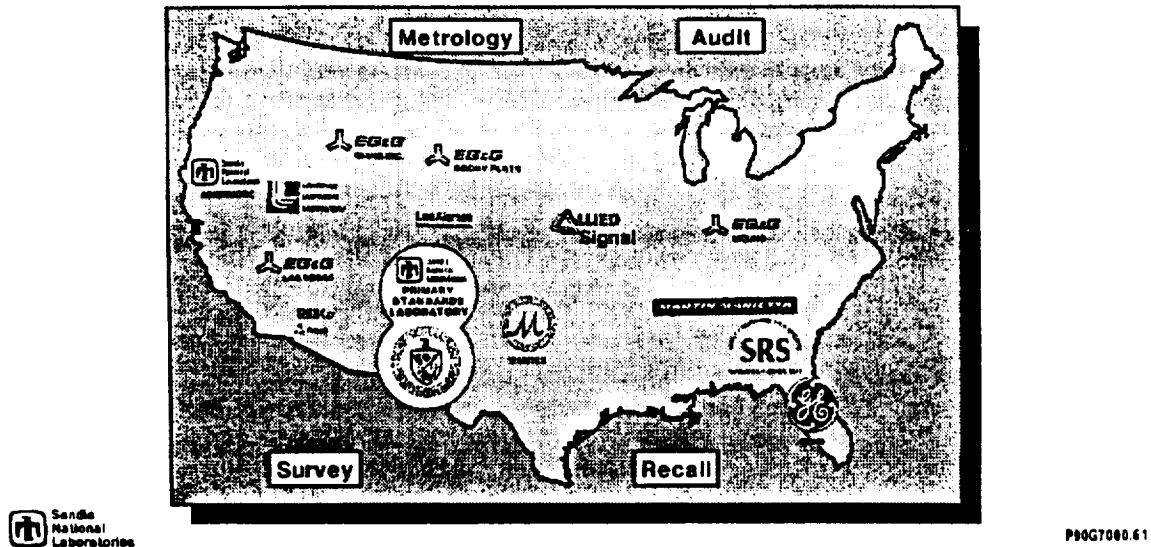
- **DOE Weapon System Metrology Program**
  - **Reconfiguration**
  - **General Operations Program**
  - **Commercial Calibration Laboratories**
- **Primary Standards Laboratory**
  - **New Building**
  - **Development**
  - **Accreditation**
  - **Programs**
  - **Documentation**



**Sandia National Laboratories**

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## SANDIA'S PRIMARY STANDARDS LABORATORY WORKS WITH A NETWORK OF INTEGRATED CONTRACTORS

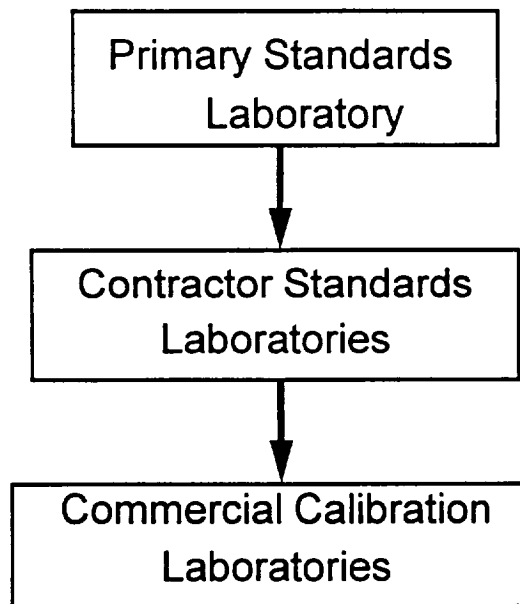


## GENERAL OPERATIONS PROGRAM

- **Combines**
  - Environmental, Safety and Health
  - Security
  - Facilities
- **Goal**
  - Single Coordinated Program
- **New Metrology Initiatives**
  - Chemical Standards
  - Ionizing Radiation

## TECHNICAL SURVEYS & MEASUREMENT AUDITS

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Sandia National Laboratories

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## COMMERCIAL CALIBRATION LABORATORIES

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- **Developing Survey and Audit Program**
  - **Criteria**
  - **Process**
  - **Reporting**
  - **Coordination**



Sandia National Laboratories

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## A New Primary Standards Laboratory is on the Way

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State of  
the Art  
Vibration  
Isolation

Humidity  
Control



Shielded from  
Electromagnetic  
Radiation

Uninterruptable  
Electrical  
Power

Ultrastable  
Temperature Control



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### DEVELOPMENT ACTIVITIES PRIMARY STANDARDS LABORATORIES

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- Josephson Volt
- Millimeter Wave Standards
- Waveform Digitizer Calibration
- Gas-Leak Compare System
- Vacuum Standard



Sandia National Laboratories

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# SANDIA - NIST AGREEMENT

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- Join Forces to Help U.S. Industry
- Combines Technical Resources
- Builds on Existing Programs at the Two Laboratories
  - Microelectronics
  - Advanced Manufacturing
  - Materials
  - Standards



Sandia National Laboratories

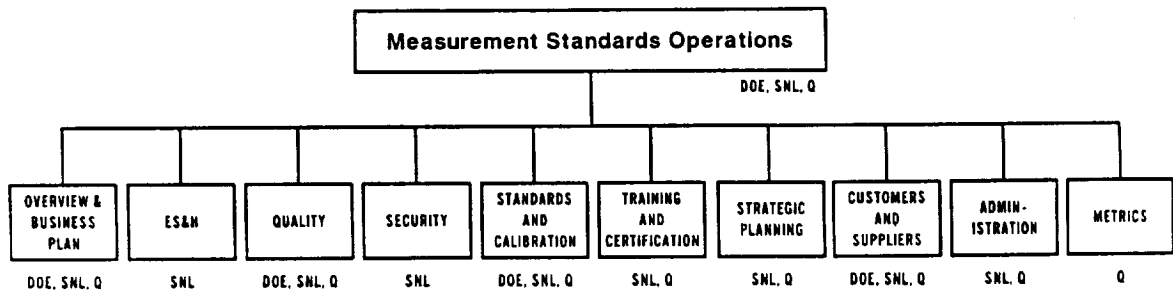
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## National Calibration Laboratory Accreditation Primary Standards Laboratory Role

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- Current Activities in Partnership with National Institute of Standards and Technology (NIST)
  - Establishing Laboratory Accreditation Criteria
  - Developing Survey/Audit Process
  - Serving as Prototype Laboratory for Accreditation
- Short-Term Goal
  - To Become Accredited
- Long-Term Goal
  - Full Partnership with NIST in Implementing the Program

## OPERATIONS AND PROCEDURES PROGRAMS



### Principal Source for Requirements

DOE

SNL

Q = Business (Quality) Plan



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## DOCUMENTATION

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- Business (Quality) Plan
- Operations and Procedures Manuals

# **Business (Quality) Plan**

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## **Organized Following Major Categories of the Malcolm Baldrige National Quality Award**

- **Leadership**
- **Management Information and Analysis**
- **Strategic Quality Planning**
- **Human Resource Development and Management**
- **Management of Process Quality**
- **Quality and Operational Results**
- **Customer Focus and Satisfaction**

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## **OPERATIONS AND PROCEDURES MANUALS**

1. **Overview**
2. **ES&H**
  - 2.1 - **Preliminary Hazard Assessment**
  - 2.2 - **Standard Operating Procedures**
  - 2.3 - **ES&H Program**
3. **Quality**
4. **Security**
5. **Standards and Calibration**
  - 5.1 - **Calibration Guidelines**
  - 5.2 - **Calibration Procedures**
  - 5.3 - **Computer Operations**
  - 5.4 - **PSLM (Primary Standards Lab Memoranda)**
  - 5.5 - **Semiannual Report**
  - 5.6 - **Technical Capabilities**
  - 5.7 - **Development and Special Measurement Projects**
  - 5.8 - **Surveys and Audits**
  - 5.9 - **Recall, Shipping and Receiving**
6. **Training and Certification**
7. **Strategic Planning**
8. **Customers and Suppliers**
9. **Administration**
10. **Metrics**

## **CONSOLIDATION OF METROLOGY ACTIVITIES**

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- **Sandia National Laboratories**
  - **Primary Standards Laboratory**
  - **Sandia Calibration & Instrument Service**
- **Separate Functions**
- **Common Management**
- **Improves**
  - **Coordination of Activities**
  - **Customer Service**



**Sandia National Laboratories**

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4/1/83

## **SUMMARY FUTURE EMPHASIS AND ISSUES**

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- **Support for Chemical Standards**
- **National Standards & Accreditation Program**
- **New Primary Standards Building**
- **Service to Customers**



**Sandia National Laboratories**

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4/1/83

## PROCESS MEASUREMENT ASSURANCE PROGRAM

Jerry L. Everhart  
EG&G Mound Applied Technologies, Inc.\*  
Miamisburg, Ohio 45343

### ABSTRACT

A high degree of competitiveness in the national and international manufacturing markets has created a demand for process controls that build quality into products, rather than relying on inspection to sort out costly rejects. Advanced metrology concepts in the calibration of inspection and test equipment will provide a means to determine and control measurement errors in manufacturing processes.

This paper describes a production Process Measurement Assurance Program (PMAP) that determines and controls measurement errors as the product is manufactured. The results of this program coupled with production Statistical Process Control (SPC) determine the product values with a known certainty. When the measurement error is determined along with the product variation, the product error is known and further inspection activities are greatly minimized or eliminated.

### NEED FOR PROCESS MEASUREMENT ASSURANCE PROGRAM (PMAP)

Competition for markets has caused manufacturers to question their reliance on inspections and re-inspections as a means of achieving quality in the products they build<sup>1</sup>. Increasingly, manufacturers want to produce quality in the products as they are manufactured, rather than relying on inspections to eliminate lesser quality products. Manufacturers have used Statistical Process Control (SPC) to determine and control the variations in products during the manufacturing process. This allows for continued improvement of processes and products. However, the SPC of products alone does not ensure that the measurement of the product is correct. In fact, measurements taken on products have hidden errors. These measurement errors are instrument errors (including standards or master errors), operator errors, and environmental influences on measurements (Figure 1).

\*EG&G Mound Applied Technologies is operated for the U. S. Department of Energy under Contract No. DE-AC04-88DP43495.



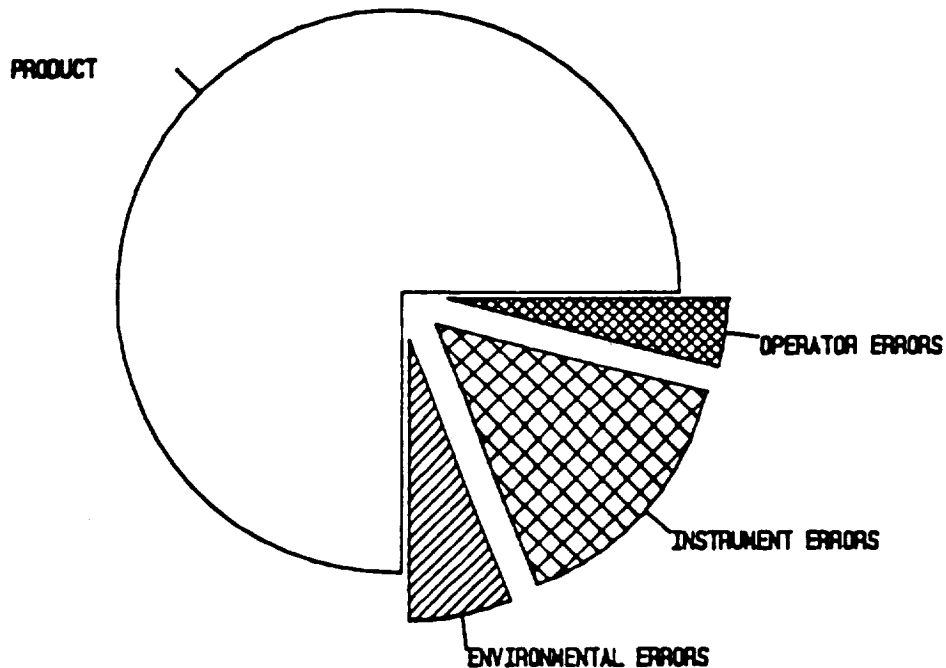


Figure 1. Measurement errors, to some degree, are in product values.

Often these measurement errors are not defined or measured, resulting in false accounts of product variability, and influencing final products. Many of these measurement errors can produce a bias or systematic error in product measurements. Rather than identifying and controlling these errors, the manufacturer often adjusts processes to meet design specifications. This can ultimately result in product deviations from design specifications. Because these errors cause unknown variations, confidence in values is lost, creating the need for re-inspections of products.

Typically, the product is inspected by the manufacturing personnel, then re-inspected by the quality department. The quality department usually checks the product with a different measuring instrument, different person, and in a different area. Many times a quality audit is performed after final inspection. These repetitive inspections result from lack of knowledge and confidence in the initial measurement. In view of this, it is of major importance that these measurement errors (instrument, operator, and environment) are evaluated, recognized, and controlled as the products are produced. This concept of parallel control of products, and control of the measurement systems (through PMAP) provides total and continuous control of the final product, and results in higher product quality at lower cost.

#### TRADITIONAL CALIBRATIONS

Measurement error in a traditional production measurement system is rectified only in a limited way by the calibration laboratory as follows: The gage or measurement instrument and its associated working standards are periodically returned to the standards and calibration laboratory for

recertification. Certifications are often performed in a controlled environment, at approximately 20°C, using calibration procedures and specifications that are written by the instrument's manufacturer for specific conditions. After calibration, the instrument is returned to the production floor and used to check product under conditions that may differ considerably from the calibration laboratory. Operators, who may not be as well trained as those in the calibration laboratory, set up and use the instrument. Under this scenario, other measurement errors are being introduced.

Another possible source of measurement error has been introduced with the use of computers and their software for operating measurement equipment and for determining results. Generally, Software Quality Assurance Programs (SQA) are in place to assure software quality; however, these programs only validate that no changes have occurred in the software code.

These conventional approaches to calibration of measurement systems are in an appraisal mode of operation, not a preventive mode. This approach may be inadequate in a high technology production environment where measurements are made by state of the art equipment.

Furthermore, it is important to address what happens when an instrument becomes defective or drifts out of its predetermined uncertainties during its calibration period. The products measured prior to the instrument's recalibration are potentially out of specification. Some investigation of both past product measurement and related errors that influence product quality are required. If the actual process measurement error is to be determined, all calibration errors and uncertainties must be calculated, including the operator and environmental influences. These errors are usually difficult to determine, and pinpointing the actual time of measurement system failure is often impossible. It is no longer acceptable to rely on post production inspection of product to segregate costly defects caused by the measurement system errors.

#### PMAP AS A CONTINUOUS CALIBRATION METHOD

A Process Measurement Assurance Program (PMAP) is a continual calibration concept for measuring equipment. This alternative approach to calibration eliminates the need of issuing discrepancy reports on measurement equipment. In addition, this approach eliminates the investigation of product that is potentially out of specification because the measurement system's performance has changed between calibration periods. One objective of PMAP is to determine, monitor, continually control, and improve the measurement capability of the measuring system in its operating environment. Initially, the measurement system's capability is established by standards laboratory personnel in the production environment after proper calibration adjustments have been made on the equipment. This determination provides the expected baseline performance level for the measurement system. Using this baseline, PMAP determines the production operator's influence on measurement error. This is a powerful tool which can be used to measure training needs for individual operators. Both the systematic error and random errors of the total measurement system are established, monitored, and controlled by PMAP while the product is manufactured. Control of the measurement system as it is being used provides control of the error in the product values resulting



from the measurement system. By comparing measurement performance to pre-established statistical limits, manufacturers can detect shifts in calibration of the measurement system prior to a manufacturing step.

As errors in the product measurements are established and statistically examined, the error in the product values can be established with a determined uncertainty. This PMAP calibration method provides confidence in the total measurement system and product values, thus allowing quality to be built into the product and eliminating or greatly reducing the need to re-inspect the product. This concept of calibration bridges the gap between the standards laboratory and the production operations.

It is important to realize that SPC methods determine only product variation, but do not determine the errors in product values. PMAP is used to determine both systematic and random errors in the values assigned to the product by the measurement system, and to maintain the calibration status of the measurement system on a continual basis.

### CONCEPT OF OPERATION

The concept of Process Measurement Assurance Program (PMAP) is based on the use of a control standard, referred to by the National Bureau of Standards as a check standard<sup>2</sup>, to statistically examine the capability of the measurement system. The control standard is chosen or manufactured to represent the product, or a specific feature of the product, for the determination of the systematic error and random variations of the measurement system. Considerations are given to the stability of the control standard value, and the amount of uncertainty of the control standard's calibrated value. Ideally the plus or minus uncertainty of the control standard's certified value should be equal to or less than the measurement system's readability. Measurement errors are determined by making measurements on the control standard with the measurement system, using the same procedures that are used when measuring the product. Initial measurements are made by standards laboratory personnel to establish confidence limits (reference limits) that can be used as a baseline to assure that the calibration is maintained. Establishing these limits often leads to immediate improvement of the measurement process.

The standards laboratory (or quality department) personnel will periodically make control measurements with the control standard using the same procedure that is used to measure the product. The frequency of these control measurements is based on the measurement system's stability, which also affects calibration periods in the traditional calibration method. If the traditional calibration period, for example would be 12 months, then enough standard reference measurements would be required to re-establish the standard reference limits for the next calibration period. It should be noted that actual physical recalibration or adjustments may not be required using PMAP. If 20 data points are sufficient to re-establish the reference limits over the 52 weeks (12 months), then standard control measurements should be performed at least once every two weeks in order to predict calibration limits for the next calibration period.

After initial reference limits are established, and the measurement interval for the standards laboratory personnel is determined, the control standard is measured by production personnel using the same procedures and operator that will be used to measure the product. This control measurement is made and recorded prior to manufacturing and measuring the product, for example at the beginning of the workday. The total measurement system is used for the control measurement; this may include a computer and its software. The measurement is checked against the pre-established confidence limits (reference limits) to assure that the system is still in calibration prior to measuring the product. A control measurement of the standard is repeated at the end of a production period (for example half of a workday) or anytime the product variations indicate a possible measurement problem. This measurement closes the loop on the measurement system's performance before the product leaves that stage of manufacturing.

The PMAP control measurements are recorded and stored according to the date and time of each measurement. Statistical determination of the upper and lower production control limits (confidence limits) is used to determine the error in the assigned values of the product for that specific production time period. Although PMAP measurements and calculations can be hand charted and calculated, computer assistance can achieve a considerable time and cost savings. When a SPC device or computer program is used to evaluate the product, it may also be capable of determining PMAP results. This PMAP concept of continual calibration, in addition to preventing re-inspection of the product, allows for extending or often eliminating routine calibration periods. PMAP tracks and assures the calibration of the measuring instrument, master (span adjustment) standards, check standards (used to minimize error linearity), and the control standard. Changes in measurement performance because of equipment, standards, or environmental influence on the measurement system are reflected by a change in the control measurement results, as are operator influences on the measurement process. Additionally, error limits in product values are determined from PMAP calculations; thus product is made and inspected by production personnel with a known uncertainty in the product values. This additional confidence in product value allows the product to be moved to its next stage of manufacturing without time consuming, expensive re-inspection.

#### PMAP CONTROL CHARTING

PMAP control charts, unlike typical SPC control charts, are designed to determine more than the random variations of a measurement system. PMAP determines the systematic error as well as the random error. The utilization of the control standard in the PMAP control chart becomes the reference by which the systematic and random errors are established.

#### Systematic Error

Systematic error of a measurement system can be caused by nonlinearity in measurement equipment, or errors in associated standards. This systematic error produces a bias in measurement results which can be determined using a control standard in the measurement system. PMAP determines this systematic error of a measurement system by subtracting the certified value of the control standard from the mean ( $\bar{x}$ ) of the control measurements. Because

traditional measurement processes ignore this systematic error, product re-inspections are common. In many cases the variability of the product may be acceptable and in control, but the product values may be out of product specifications because of the systematic error of the measurement system (Figure 2).

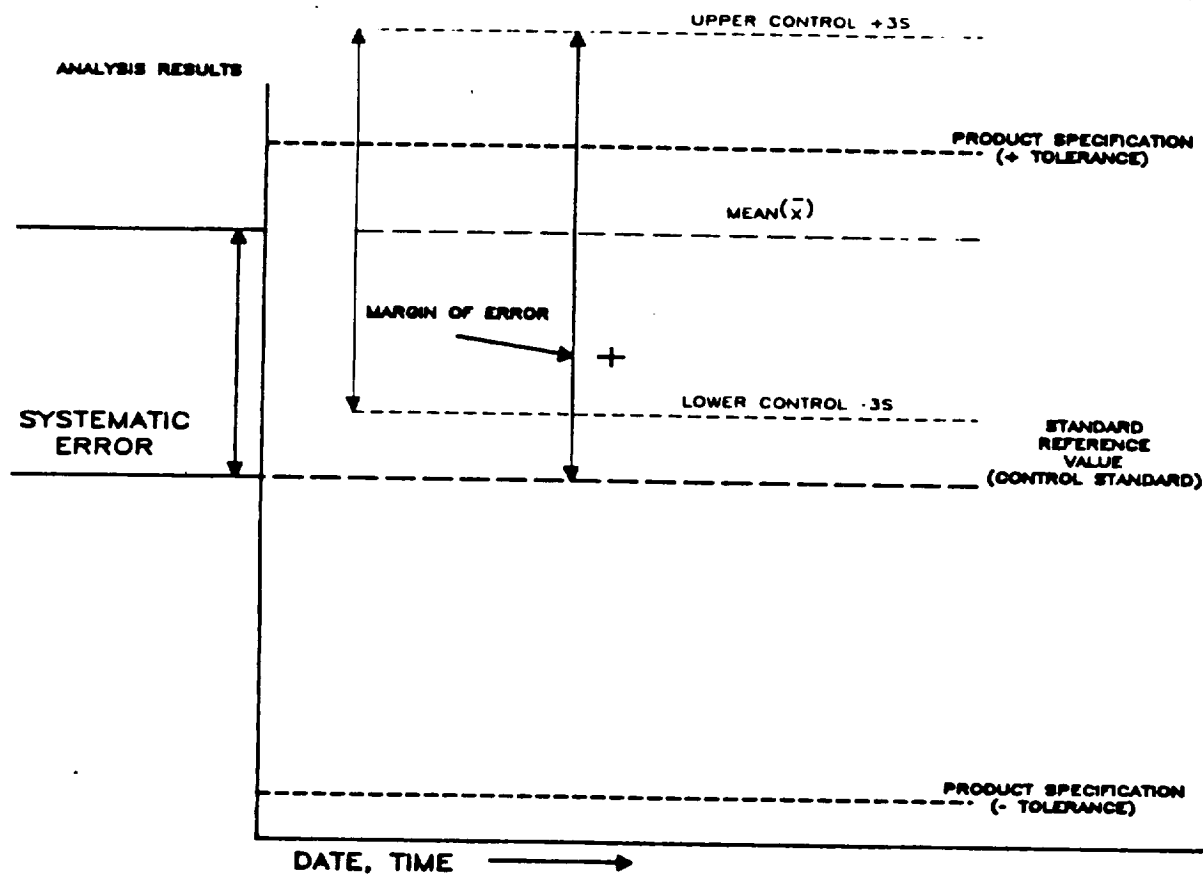


FIGURE 2. The systematic error of a measurement system is revealed by PMAP control chart.

Systematic error of the measurement system is defined as follows:

$$\begin{aligned} \text{Systematic error} &= \sum x_i / n - CS \\ &= \bar{x} - CS \end{aligned} \quad (1)$$

Where  $\bar{x}$  = Mean of PMAP control standard measurements

$x_i$  = PMAP control standard measurements

$n$  = Number of PMAP control standard measurements

$CS$  = PMAP control standard certified value

### Random Variability

Random variability of a measurement system is the inability of the measurement system to repeat the same measurement results. The random variability of a measurement system can result from any or all of the previous sources of error, with the exception of a nonlinearity error, which always results in a systematic error. The random variability of a measurement system is determined by analyzing the PMAP control standard measurements to establish the variability around the mean ( $\bar{x}$ ) of the measurements. The variability is described by the conventional three standard deviation method where 99.7% of the measurements are expected to fall within the three sigma probability. A change in the measurement system's ability to repeat a measurement within limits is reflected each time the standard deviation is recalculated at recalibration intervals. PMAP continually checks for any significant change in the production measurement system's ability to repeat a measurement by immediately plotting each control standard measurement against the pre-established 3s reference confidence limits before the product is manufactured (Figure 3).

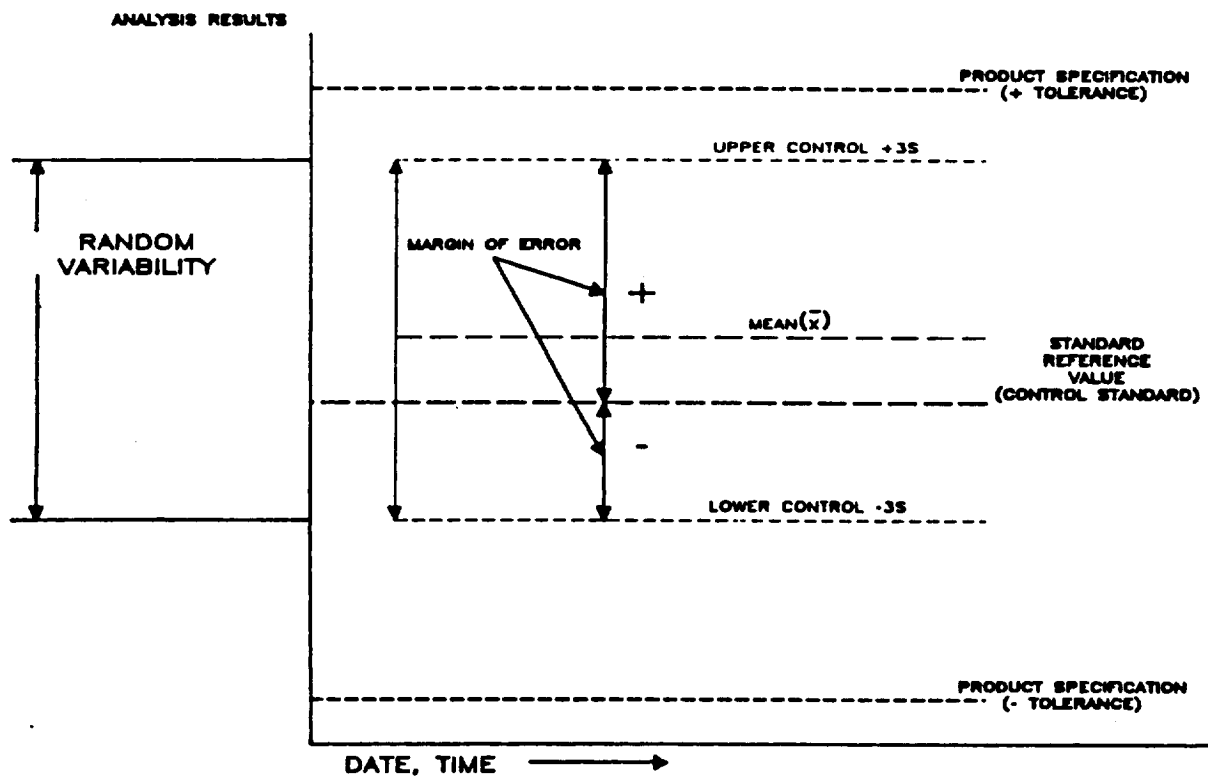


FIGURE 3. The random variation of a measurement system is revealed by PMAP control chart. The system's performance is continually evaluated by plotting each control measurement before manufacturing the product.

Measurement variability or 3 sigma limits are defined as follows:

$$\text{Upper PMAP (+3s) limit} = \bar{x} + 3\left(\sqrt{\sum(x_i - \bar{x})^2 / n - 1}\right) \quad (2)$$

$$\text{Lower PMAP (-3s) limit} = \bar{x} - 3\left(\sqrt{\sum(x_i - \bar{x})^2 / n - 1}\right) \quad (3)$$

Where  $\bar{x} = \sum x_i / n$

$x_i$  - PMAP control standard measurements

$n$  - Number of PMAP control standard measurements

## PMAP RESULTS

### Measurement System Error

PMAP defines the total measurement system error as the result of all systematic and random influences on the measurement system's ability to determine the control standard's certified value. The error is determined by subtracting the certified value of the control standard along with its affiliated uncertainty from the upper and from the lower 3s reference limits. This error is calculated from the control measurements made by Standards Laboratory or quality personnel.

Measurement system error limits are defined as follow:

$$\text{Positive Margin of Error} = U3s - CS + Un \quad (4)$$

$$\text{Negative Margin of Error} = L3s - CS - Un \quad (5)$$

Where:

$U3s$  - Upper 3s reference limits

$L3s$  - Lower 3s reference limits

$CS$  - PMAP control standard certified value

$Un$  - Control standard uncertainty

(The control standard's uncertainty is applied to the error determination so that the total measurement error can be established.) These error determinations are based on the control standard measurements made by standards laboratory or quality personnel and determine the measurement system's calibration status. At recalibration intervals, the systematic error and random variability are re-calculated to determine new 3s reference limits until the next calibration interval. The T test is used to determine if the systematic error is within expected range of the previous error. The F test is used to determine if the random variability has significantly changed<sup>3,4</sup>.

T test and F test are defined as follows:

$$T \text{ test} = \frac{\text{bias new} - \text{bias old}}{\text{standard dev old}} \quad (6)$$

$$F \text{ test} = \frac{(\text{standard dev new})^2}{(\text{standard dev old})^2} \quad (7)$$

If these tests reveal significant changes in the measurement systems performance, re-adjustment or recalibration may be required. If both tests are in control, then these reference limits are used for the next calibration interval (Figure 4).

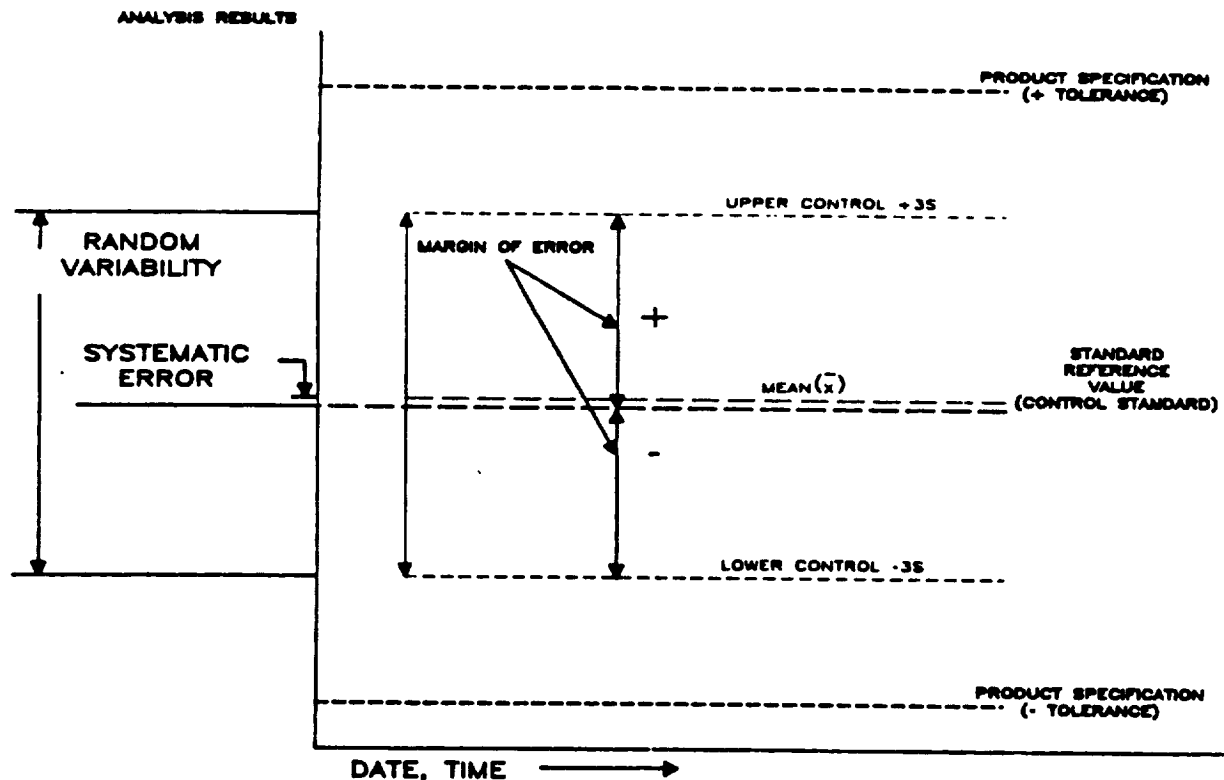


FIGURE 4. The total measurement system error is a result of all systematic and random influences as it is revealed by PMAP control chart.

## Error in Product Values

The confidence in product values comes from establishing the error in the product values. This confidence is expressed as possible error or uncertainty that may be present in each product value. This product uncertainty is established by analyzing the production personnel's PMAP measurements of the control standard. The production control standard measurements are analyzed over the specific time period which was required to manufacture and measure the product. The PMAP control standard is subtracted from the upper and the lower production control 3s limits to determine product error limits. The certified uncertainty of the control standard is applied to the error limits to establish the possible error or possible uncertainty in the product values for that specific lot of product. Refer to equations 8 and 9.

Product error limits are defined as follow:

$$\text{Upper Product Error Limit} = U3s - CS + Un \quad (8)$$

$$\text{Lower Product Error Limit} = L3s - CS - Un \quad (9)$$

Where:  $U3s$  = Upper PMAP production 3s limits  
 $L3s$  = Lower PMAP production 3s limits  
 $CS$  = PMAP control standard certified value  
 $Un$  = Control standard uncertainty

## Uncertainty in Product Values

The upper and lower product error limits (equations 8 and 9) are a valuable tool that allow production personnel to adjust the process specification limits to guarantee that product is within design specifications. The product specification limits can be shifted by subtracting the lower error limit (9) from the upper product design specification and by adding the upper error limit (8) to the lower product design specification. The results of these new process specification limits compensate for total measurement error and guarantee acceptable product without re-inspection.

## SUMMARY

The Process Measurement Assurance Program (PMAP) is a method of continual calibration that puts quality process controls in the calibration of measurement systems. The application of PMAP is important to the production environment, but it should be noted that these concepts apply to any process where the results are determined by a measurement system. PMAP provides a system calibration that evaluates the performance of the total measurement system in the manner in which it is used. The benefits of this calibration method are preventive, not appraisal. Any out of control situations due to equipment, environment, personnel, or standards are detected immediately. These detections reduce production rejects.

It is also important to realize that the implementation of a PMAP requires a thorough knowledge of the specific measuring equipment and the direction of a metrologist who can select control standards and procedures that meet the requirement described in this report.

The results of PMAP implementation provide for the manufacturing of a product with values of a known certainty without repeated inspection. This statistical approach to calibration provides continual calibration and continued improvements to measurement processes.

#### REFERENCES

1. Deming, W.E., 1982, "Quality, Productivity, and Competitive Position", Massachusetts Institute of Technology, Center for Advanced Engineering Study, pp. 19-22.
2. Croarkin, Carroll, 1977, "Measurement Assurance Programs Part II: Development and Implementation" Special Publication 676-II, National Bureau of Standards, pp. 19-20.
3. Rickmers, A.D. and Todd, H.N., 1967, "Statistics An Introduction", McGraw-Hill, Inc., pp. 21-22, pp. 66-68.
4. Varner, R.N. and Raybold, R.C., 1980, "National Bureau of Standards Mass Calibration Computer Software" Technical Note 1127, National Bureau of Standards, pp. 14-23.



# NIST PRESENTATIONS



**Measurement of Flow, Temperature,  
Humidity, and Transient Pressure**

***or***

***Research and Measurement Services  
of Potential Interest to the  
NASA Metrology and Calibration Working Group***

**Greg Rosasco  
Process Measurements Division  
Chemical Science and Technology Laboratory  
presented at  
16th Annual NASA Metrology & Calibration Workshop  
April 20-22, 1993**

# **TEMPERATURE**

***Dr. Billy W. Mangum***  
***(301) 975 4808***

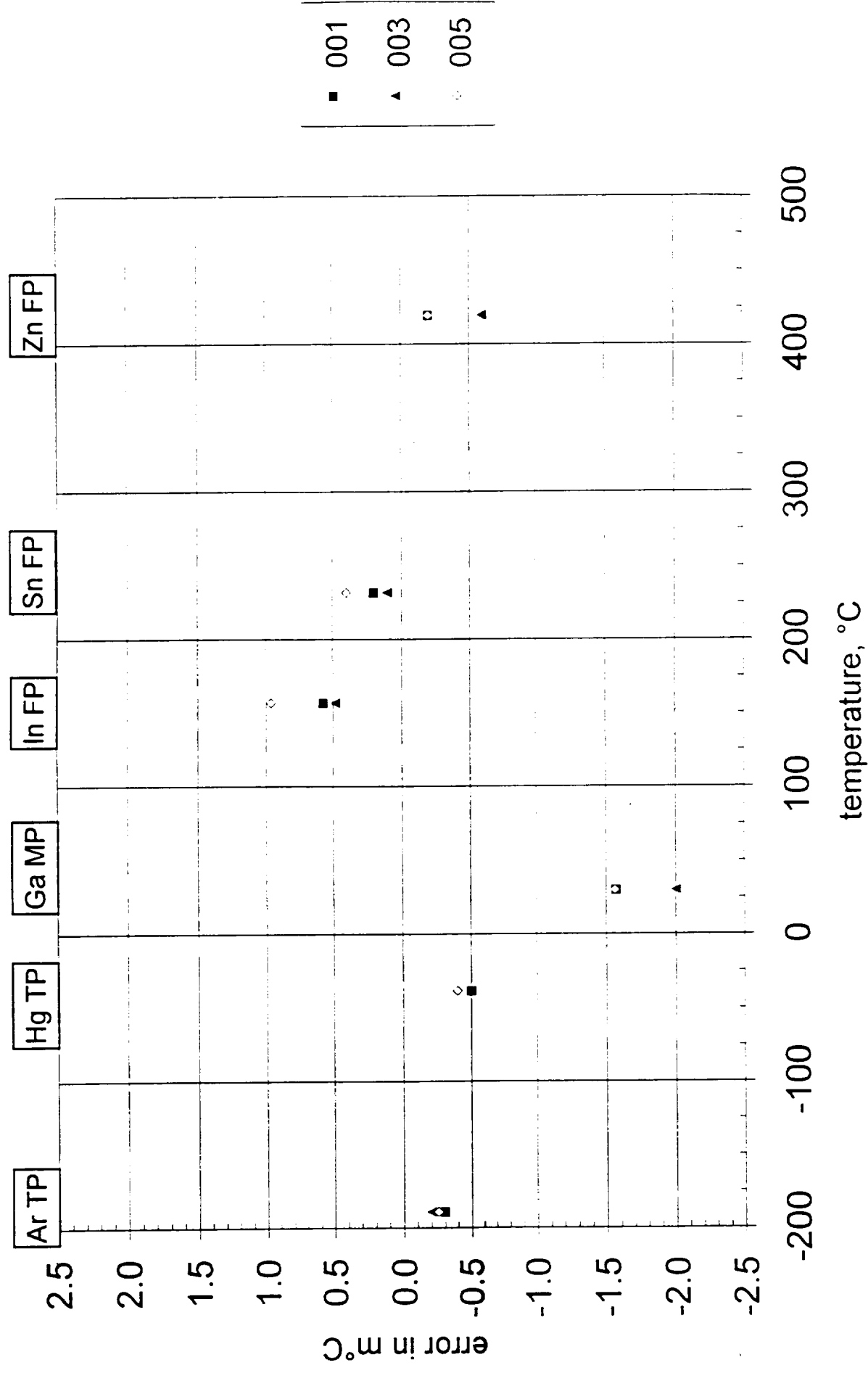
***Calibration Services ITS-90 from 0.65 K to 1235 K***

***Measurement Assurance Programs***

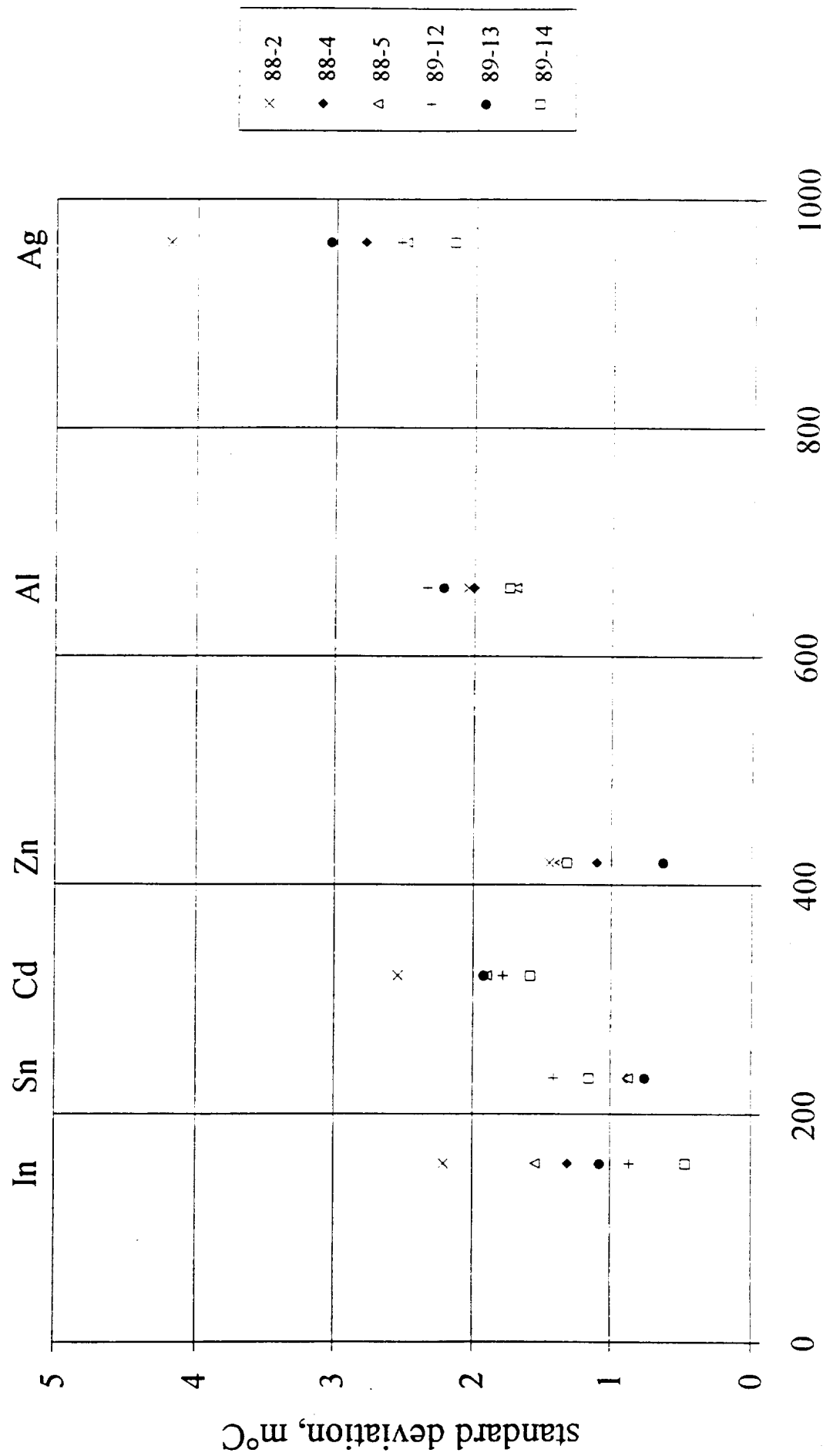
***Improvements in thermocouple technology***

- Stability of Au/Pt TC's***
- Frequency response of thin film TC's***

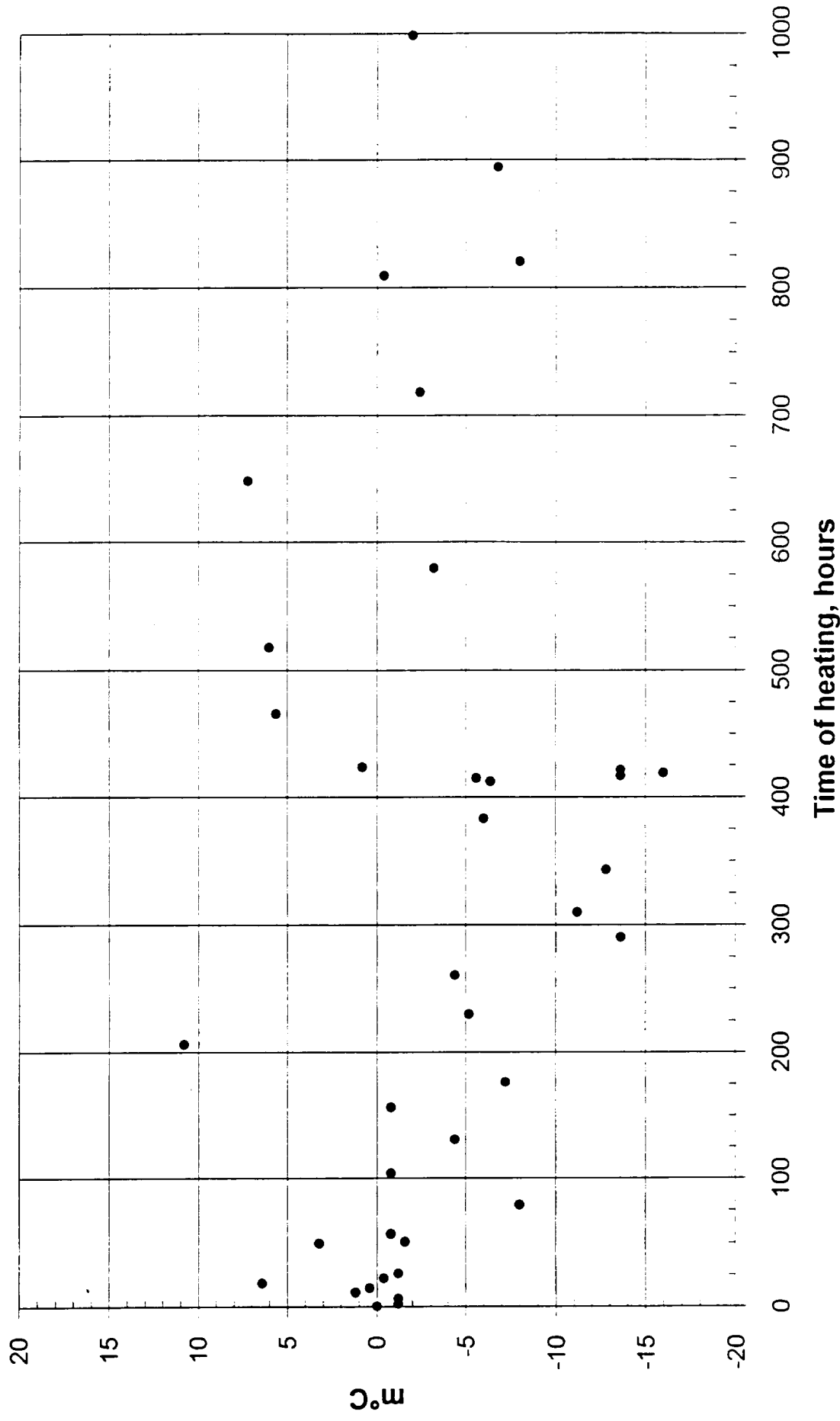
# Error in MAP Participant Calibrated SPRTs Relative to NIST Calibrated SPRTs at Various Fixed Points

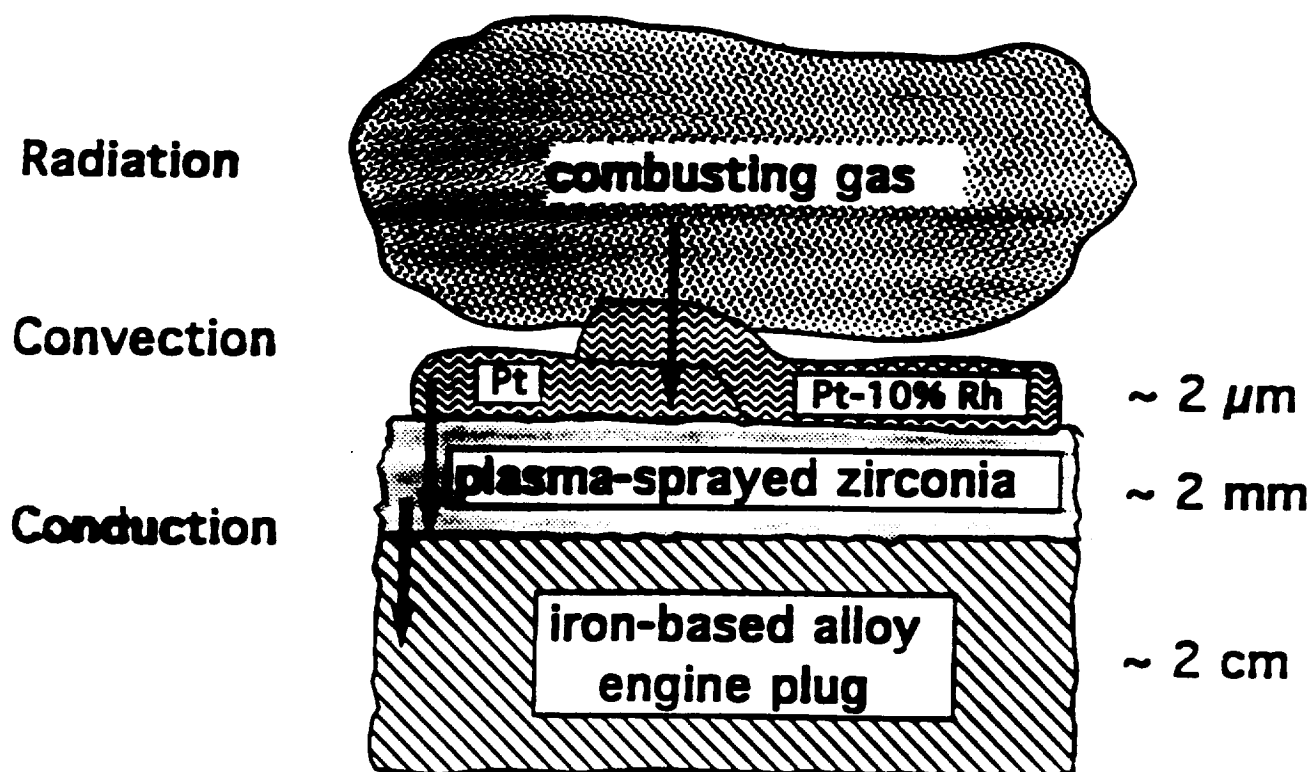


# Reproducibility ( $1\sigma$ ) of Au/Pt Thermocouples at the Freezing Points of In, Sn, Cd, Zn, Al, and Ag



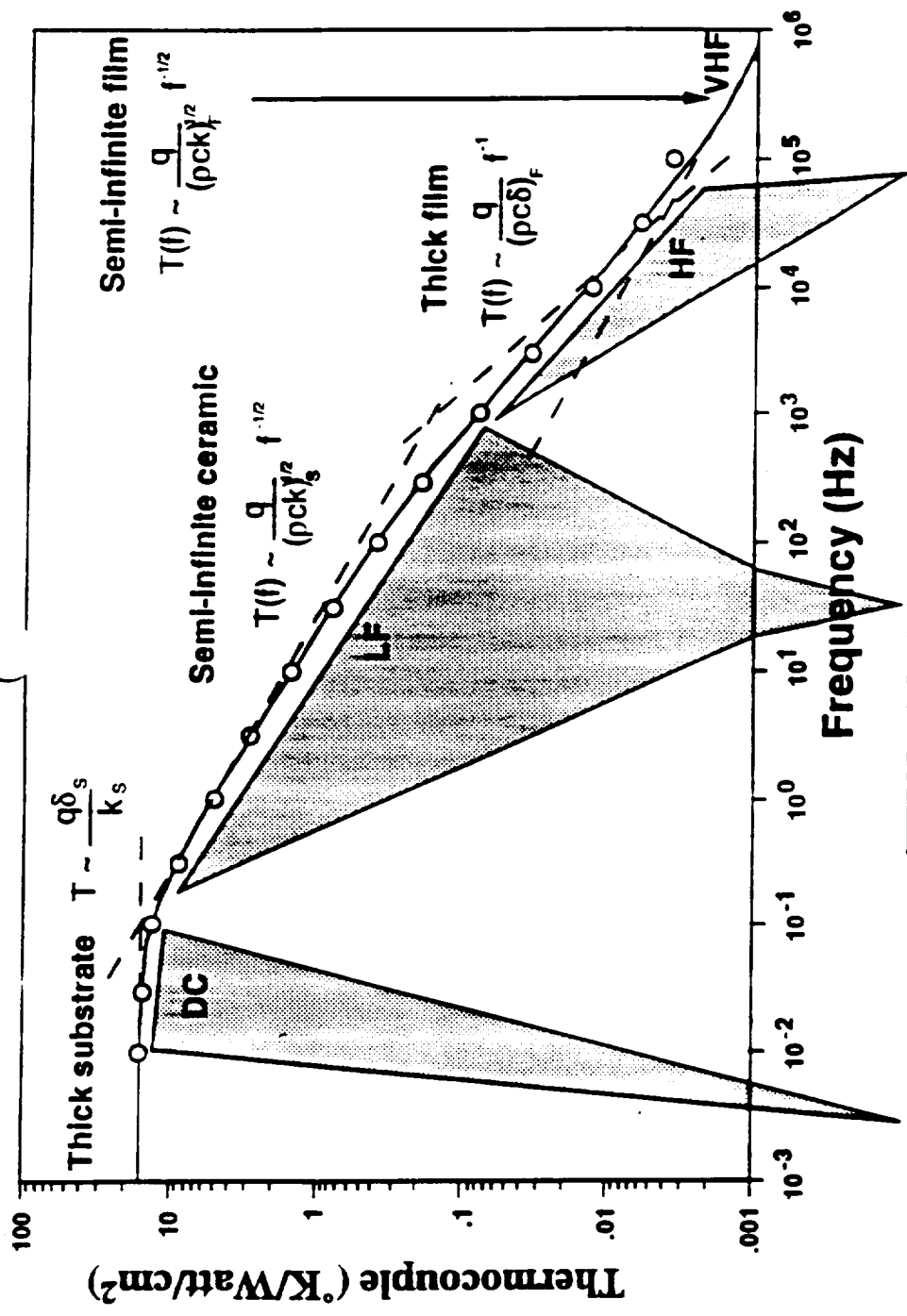
**Change in Indicated Temperature of a Gold vs. Platinum  
Thermocouple (SC88-3) at the Silver Freezing Point (961.78 °C)  
with Time of Heating at about 962 °C**



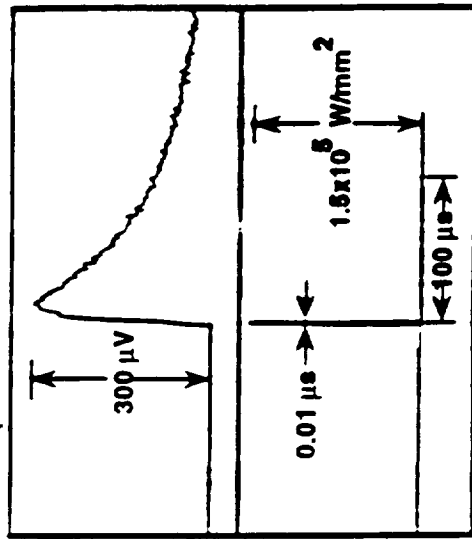
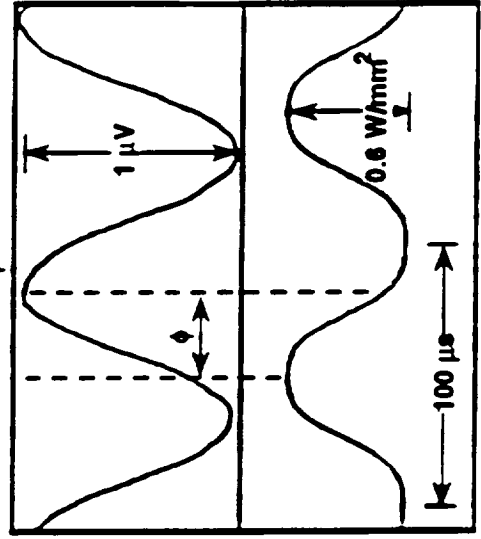
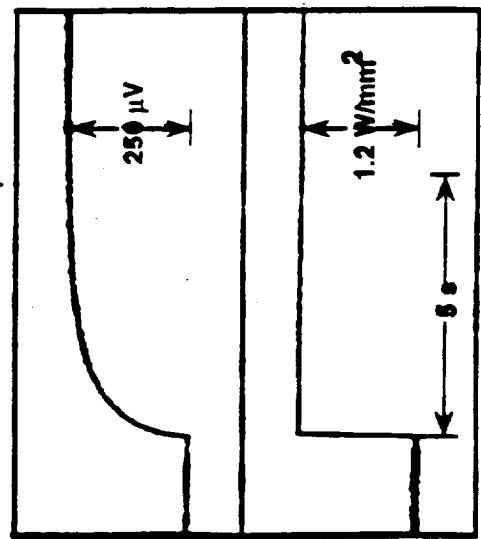


1. **DC Response** ( $< 1 \text{ Hz}$ )  
 -transparent film, thin ceramic  
 -"watt meter"
2. **Step Input Frequency Response** (seconds)
3. **Low Frequency Response** ( $0.1 - 1000 \text{ Hz}$ )  
 -semi-infinite ceramic
4. **High Frequency Response** ( $1 - 100 \text{ kHz}$ )  
 -thin film  
 -"joule meter"
5. **Step Pulse Frequency Response** (microseconds)
6. **Very High Frequency Response** ( $> 100 \text{ kHz}$ )  
 -semi-infinite film





LASER THERMOCOUPLE



DC STEP

MODULATED

IMPULSE

# **FLOW**

***Dr. George E. Mattingly  
(301) 975 5939 (G'burg)  
Ms. Patricia J. Giarratano  
(303) 497 3110 (Boulder)***

## ***Flow Calibration Services***

- Liquids, gases, cryogenic fluids (Boulder)***

## ***Round Robin Tests***

- Mass flow controllers***
- Turbine meters***

## ***Installation effects research***

## ***Special meter developments***

## ***Cryocooler systems for space applications***

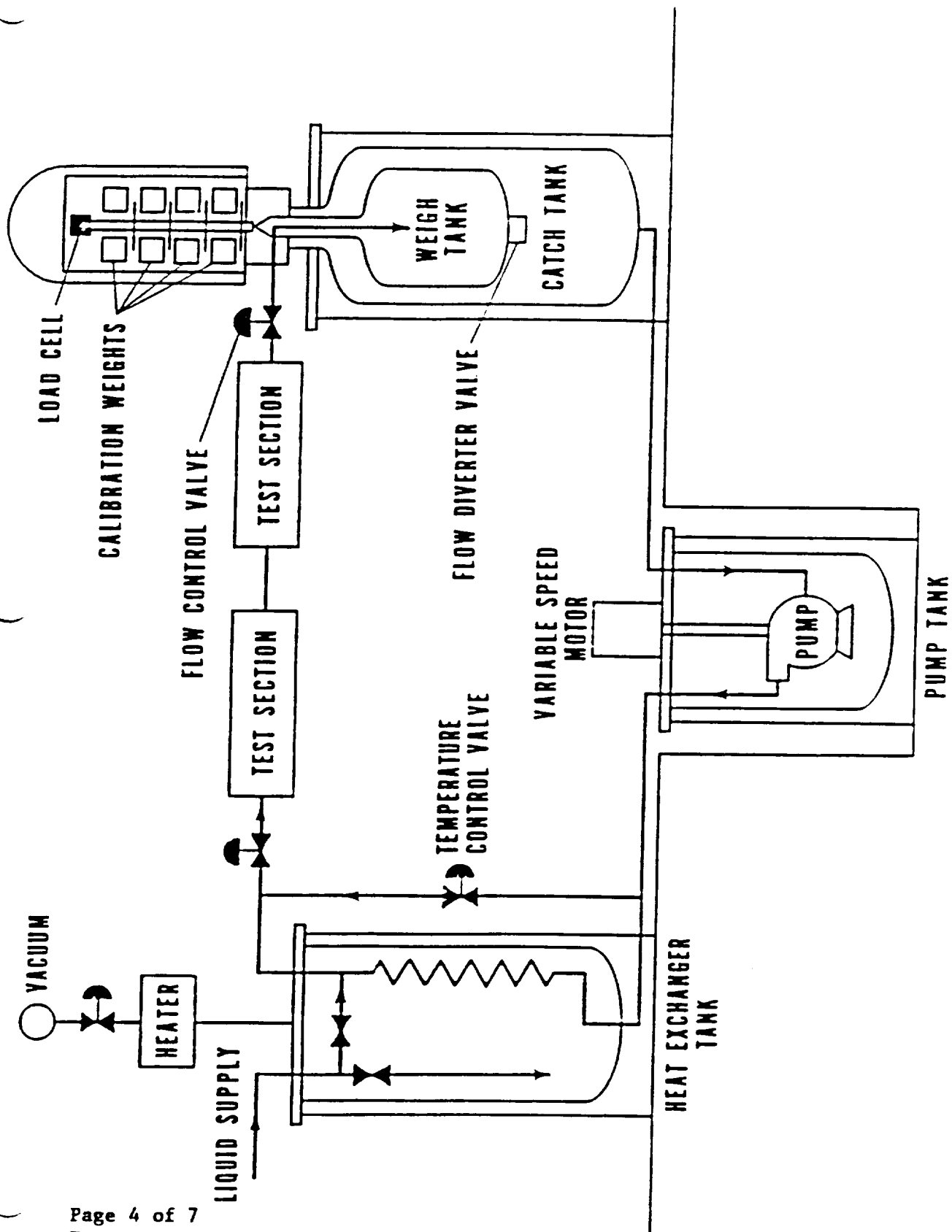
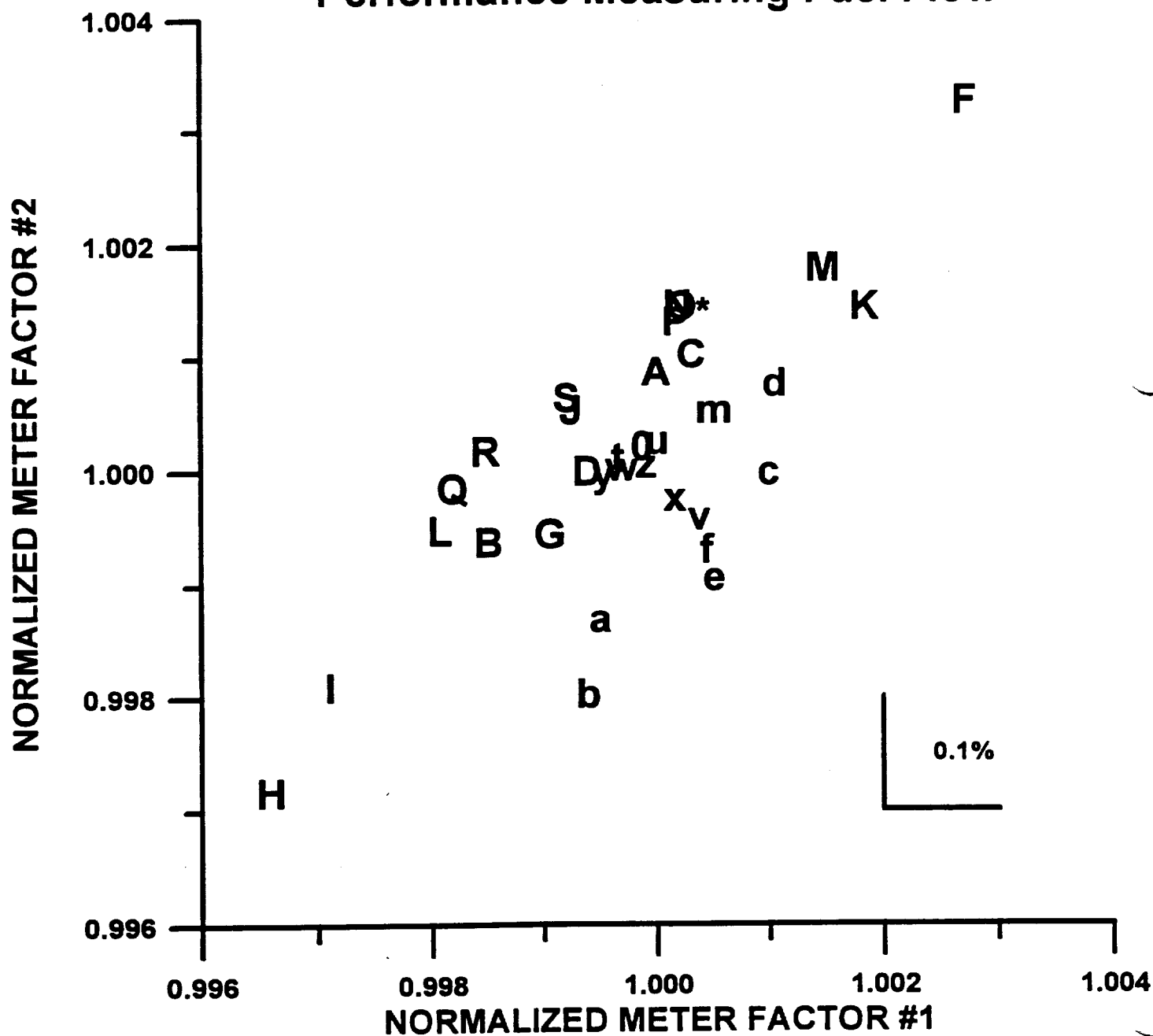


FIGURE 1. FLOW SCHEMATIC OF LIQUID NITROGEN FLOW FACILITY.

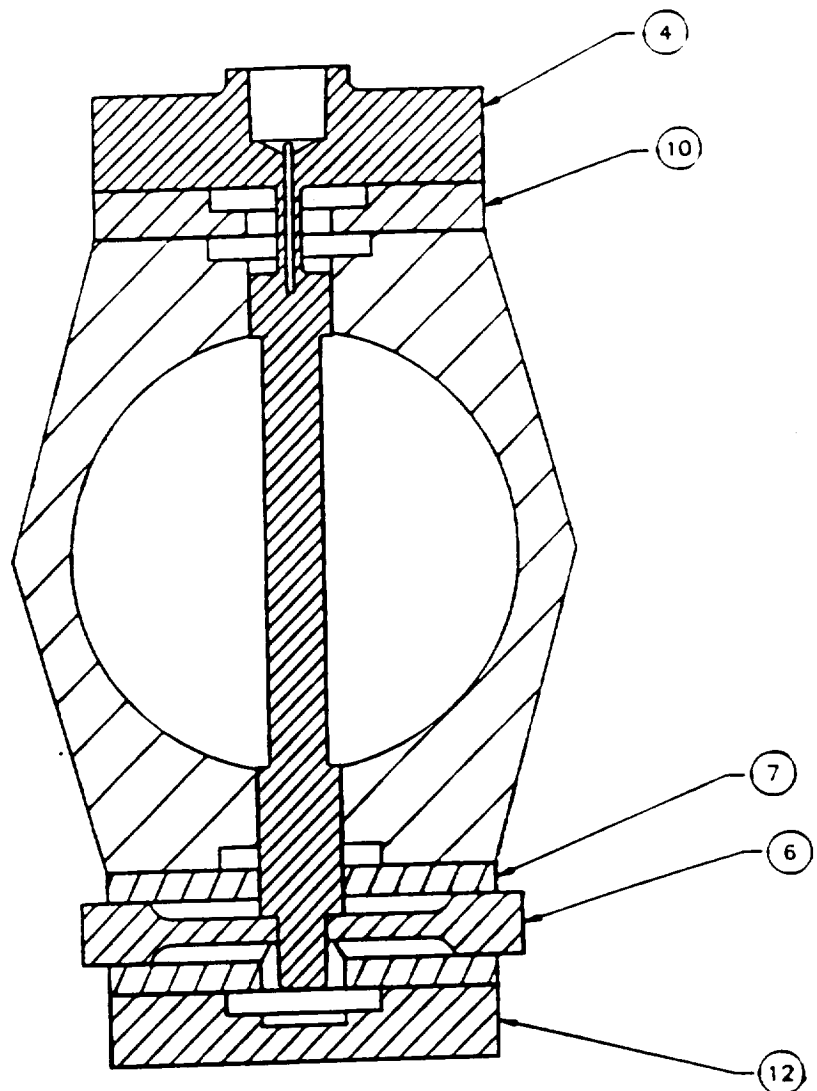
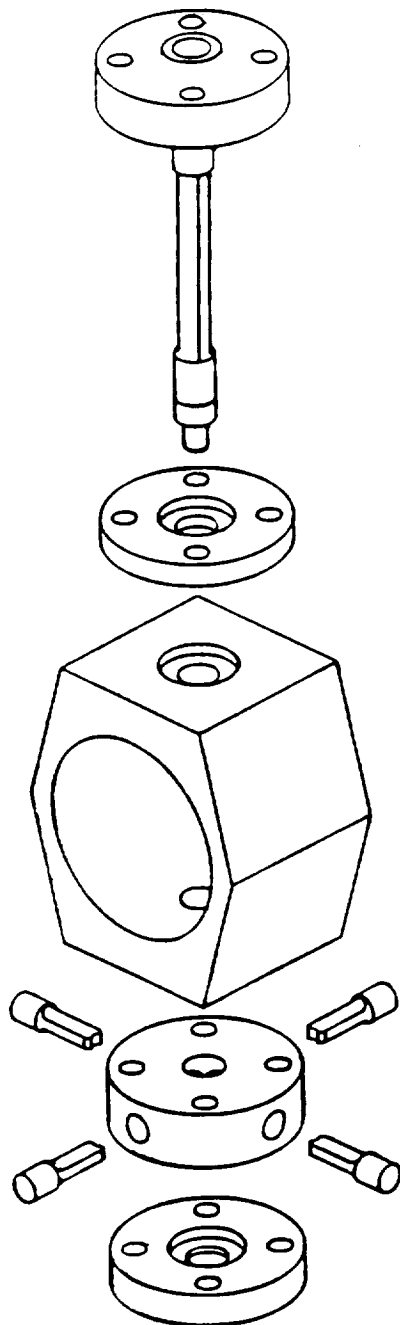
# Youden Plot for Calibration Facility Performance Measuring Fuel Flow



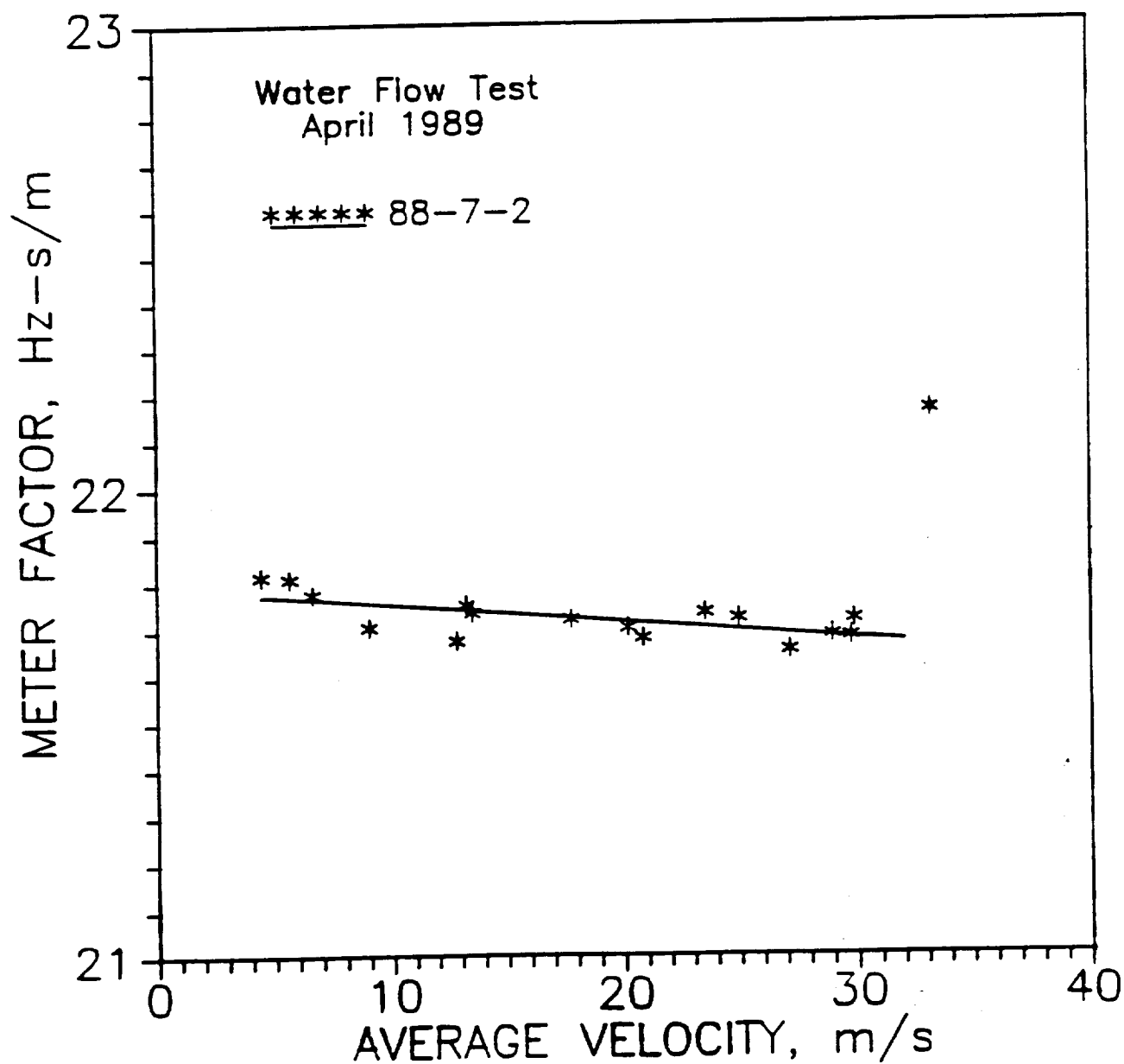
VORTEX SHEDDING

Flow Meter

RANGE TO 40 M/S



ORIGINAL PAGE IS  
OF POOR QUALITY



***Cryocooler systems for space applications***

***Dr. Ray Radebaugh  
(303) 497 3710 (Boulder)***

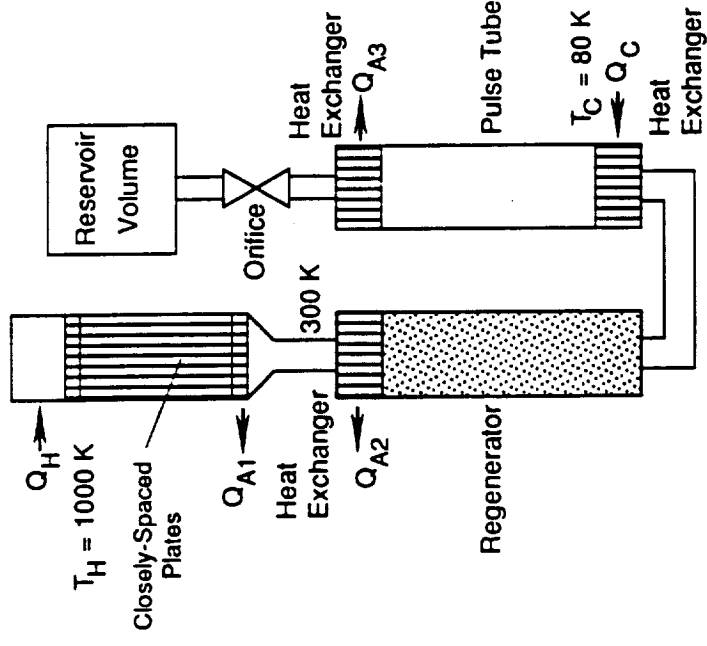
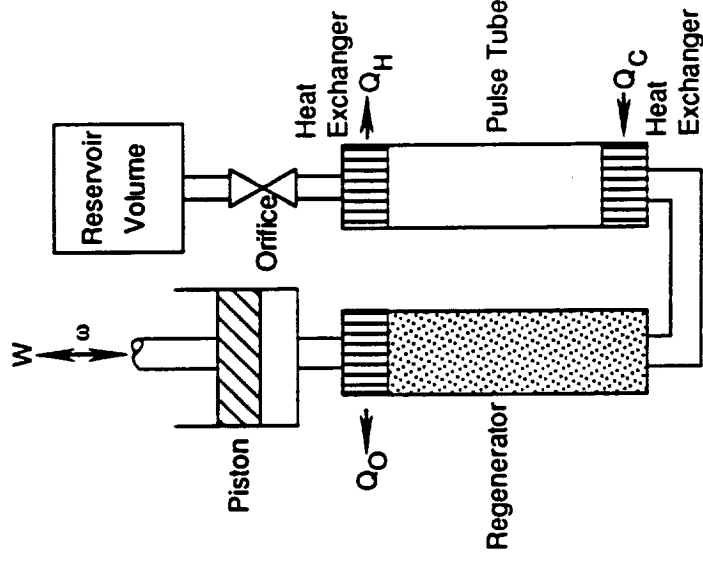
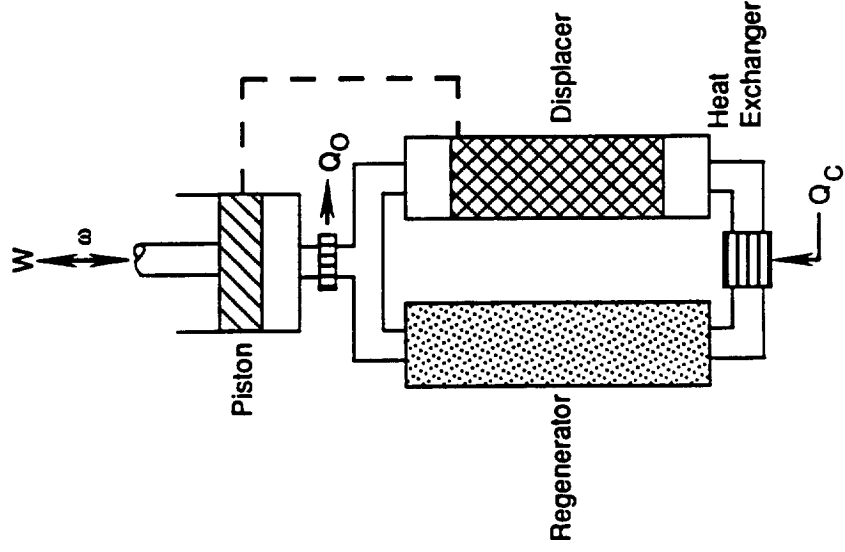
***Lubrication free, dual-opposed compressors***

***Regenerative cryogenic refrigerators***

***Orifice pulse-tube refrigerators (OPTRs)***

***Thermoacoustically driven OPTRs***

**Approach:** Reduce number of moving parts.





# **HUMIDITY**

***Dr. James R. Whetstone  
(301) 975 2738***

***Under development***

***New absolute standards to 100 ppm(vol)***

- Packaging - semiconductor electronics***

***Low frost-point generators to 10 ppb(vol)***

- Process gases***

***Measurement capability to ppb range***

# Summary

## -identified approach

- = molecule "imbedded" in source
  - + frequency and damping of molecular oscillator
  - + populations of rotational levels

- = time response determined by molecular response to local T and P conditions

- = signals derived from laser sources

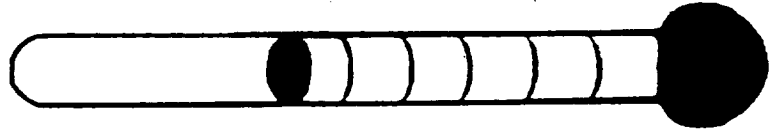
- = measurements in nanoseconds

- design, build, and characterize

## REFERENCE DYNAMIC SOURCE

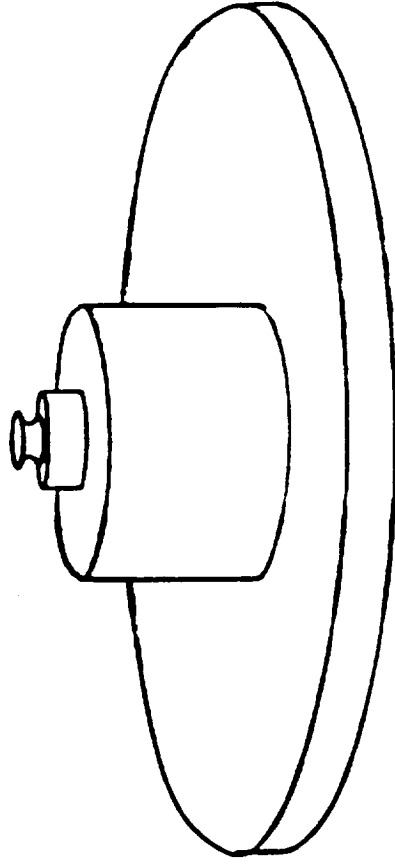
GOAL: 5% accuracy in P and T  
rise times of  $1 \times 10^{-6}$ s

RANGE: 100 kPa - 100 MPa (1000 atm)



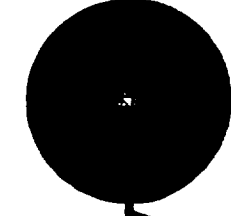
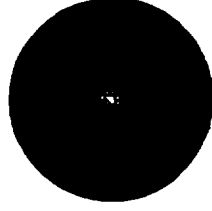
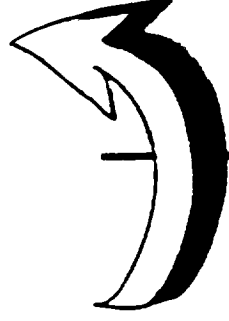
Kelvin

$\text{Kg (m / s}^2\text{) / m}^2$



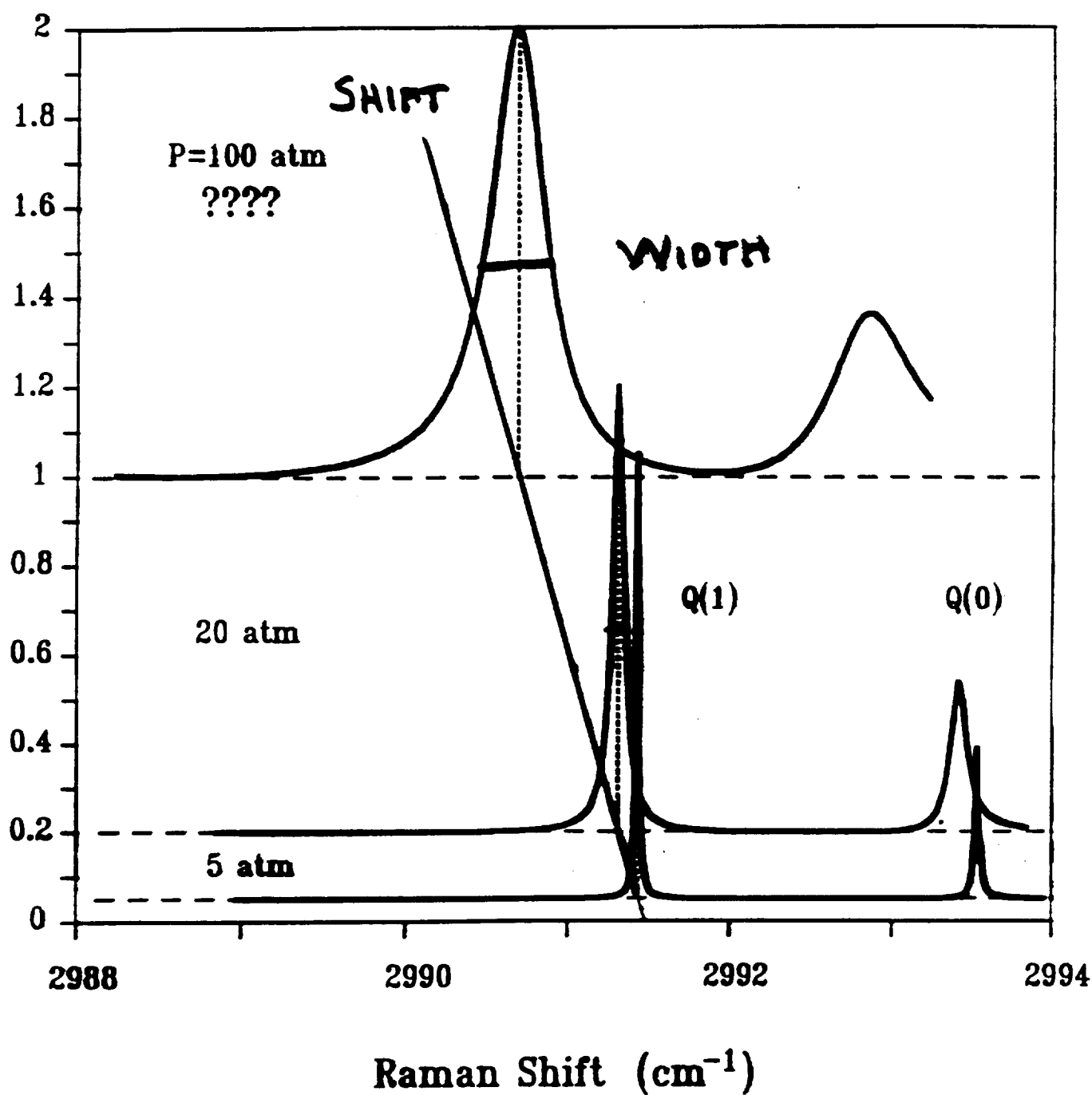
$\text{D}^2$

rotate



vibrate

D<sub>2</sub>:Ar (0.1:0.9) vs. P



PREDICTED  
CARS - SPECTRUM figure 6

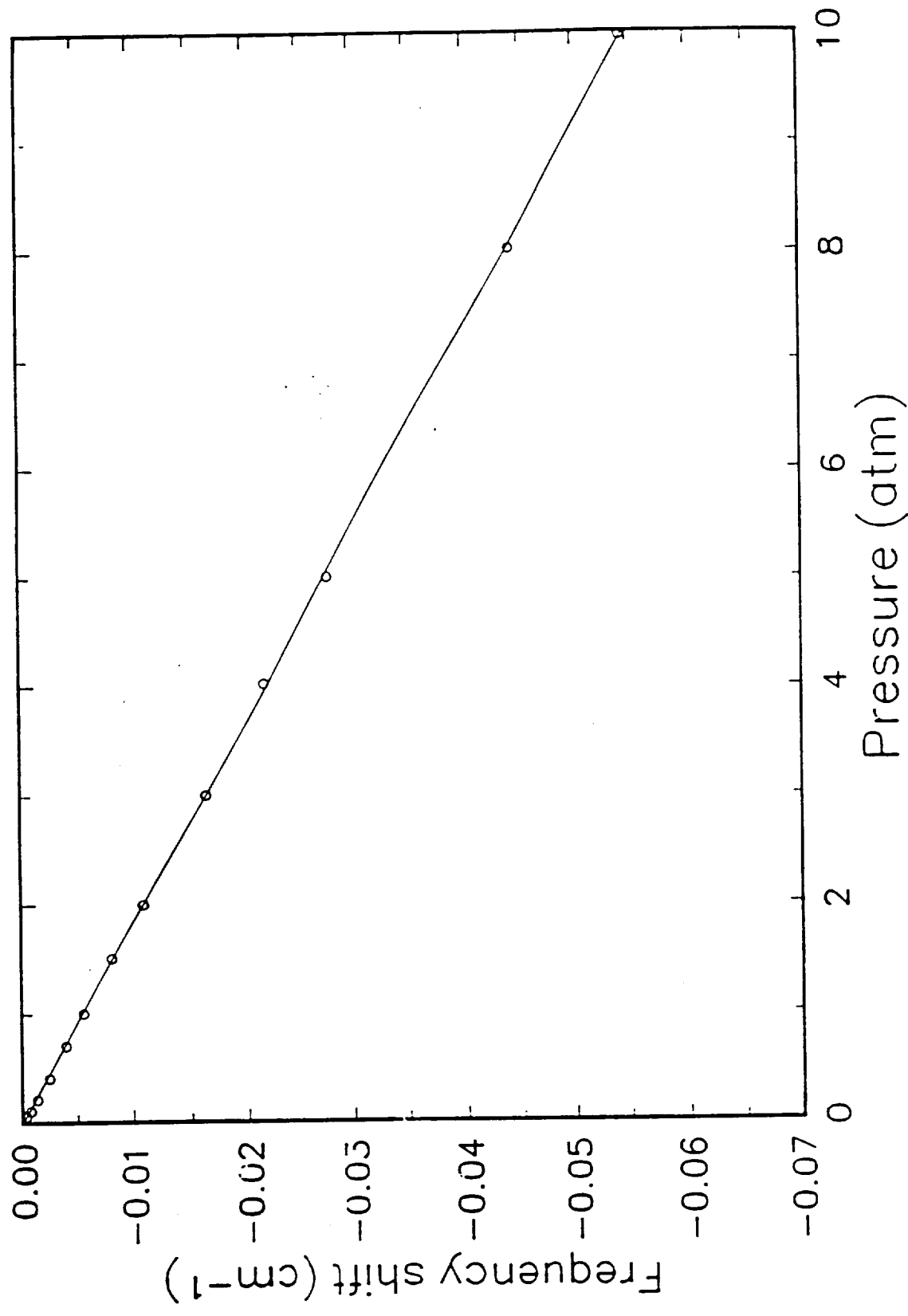
$D_2:N_2$  [0.1:0.9]  
295 K

1000xdata 0.05 atm  
1.6xdata 1.0 atm  
1.0xdata 4.0 atm  
1.0xdata 10.0 atm

CARS Signal

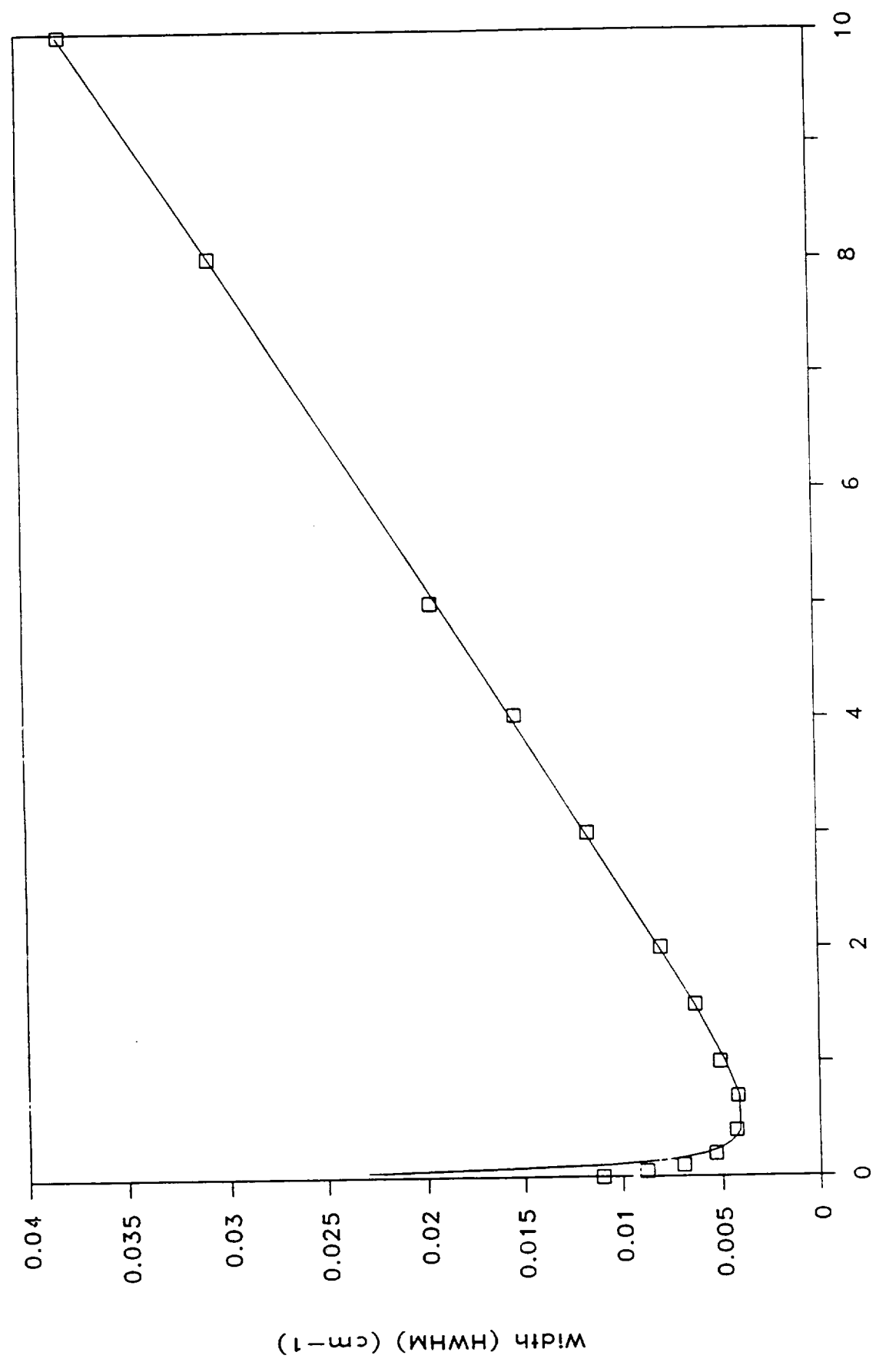
Raman Shift ( $cm^{-1}$ )

D<sub>2</sub>:N<sub>2</sub> (0.1:0.9)  
295 K



( (


D2:N2 [0.1:0.9] 299 K Width



□ Lor/HC fit width  
Pressure, atm — [Defl/P + P\*gamma]






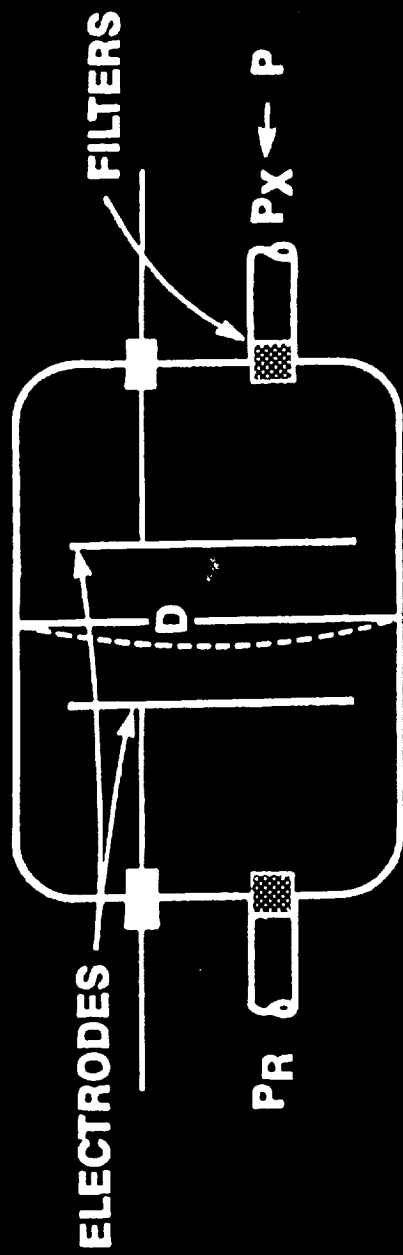


# Development of Improved Low Pressure Transfer Standards

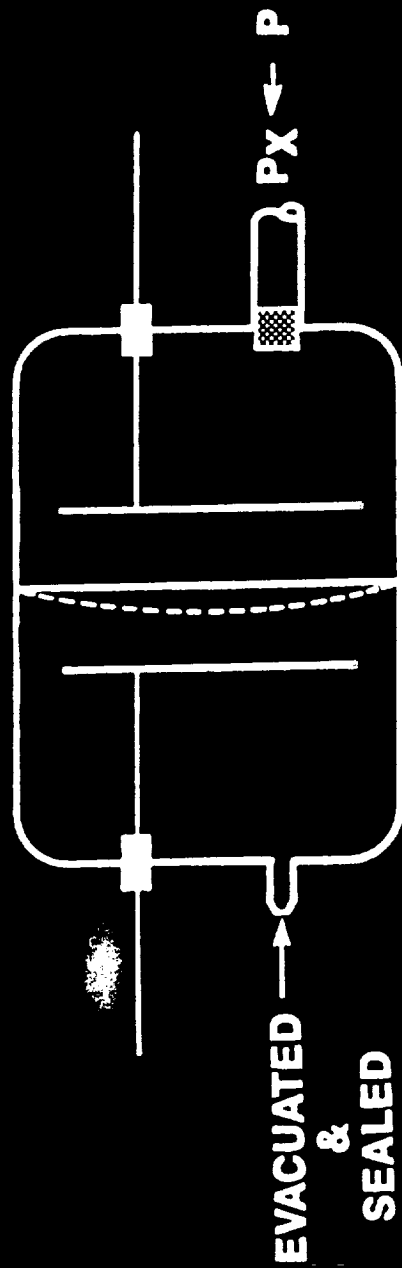
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Archie P. Miller and Charles Tilford  
Thermophysics Division  
National Institute of Standards and Technology





**DIFFERENTIAL**



**ABSOLUTE**

# CAPACITANCE DIAPHRAGM GAGES

- ATTRACTIVE FEATURES

Compatible with High Vacuum

"True" Pressure Measurement

High Sensitivity

- LIMITING PROBLEMS

Zero Instability

Thermal Transpiration

Response Function or "Calibration Factor" Shifts

# PROPOSED APPROACH

- DEVELOP A HYBRID "ROOM" TEMPERATURE CDG

Adapt a Thermoelectric Module to a Commercial CDG

- > addresses the thermal transpiration problem
- > temperature control for improved zero stability

- DEVELOP A FUSED QUARTZ DIAPHRAGM CDG

Low - Stress "Thick" Diaphragm constructed from Fused Quartz

- > should reduce shifts in the "Calibration Factor"

Reduced Sensitivity can be more than compensated for by

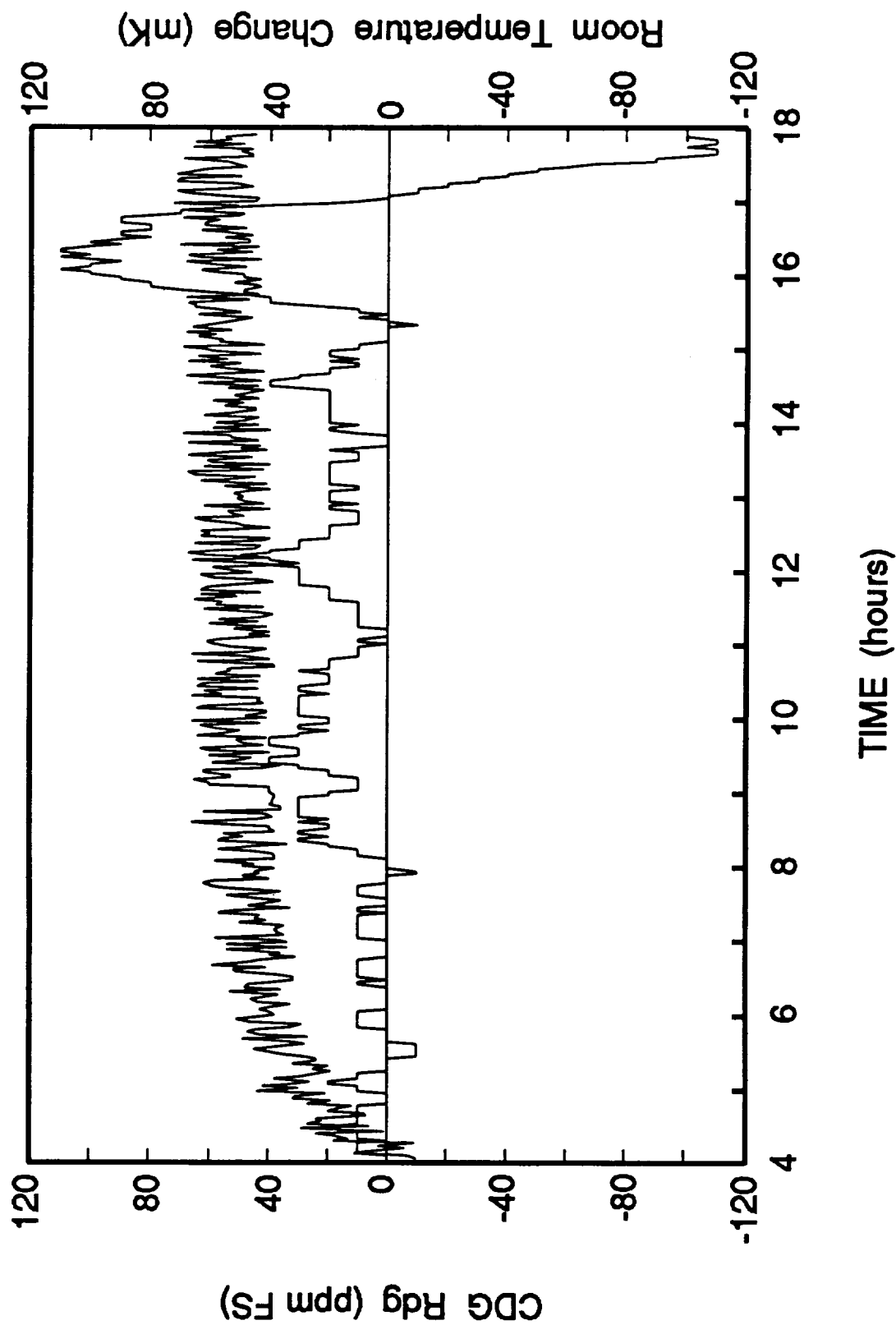
3 - Terminal Capacitance Measurement Techniques

(

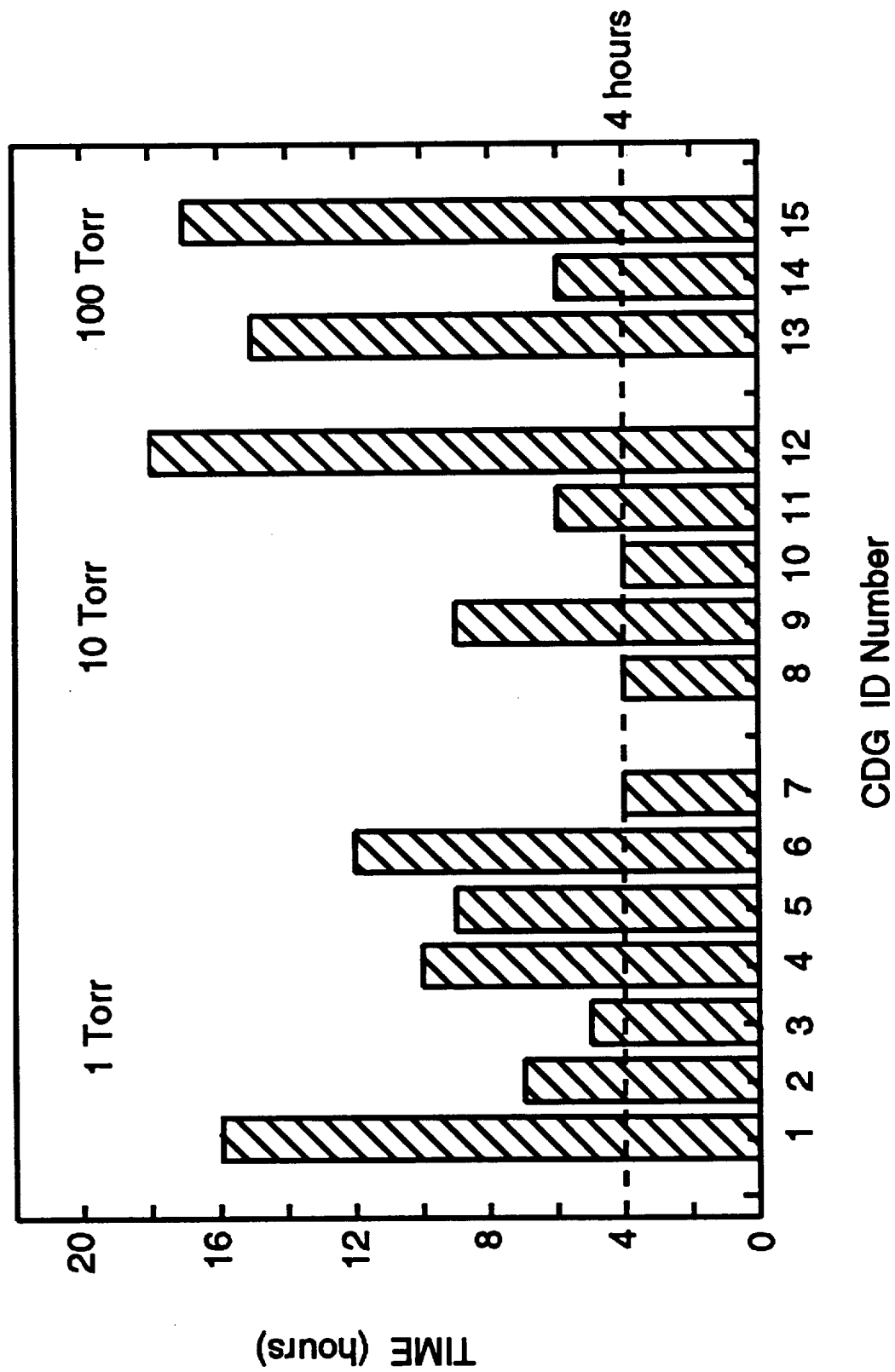
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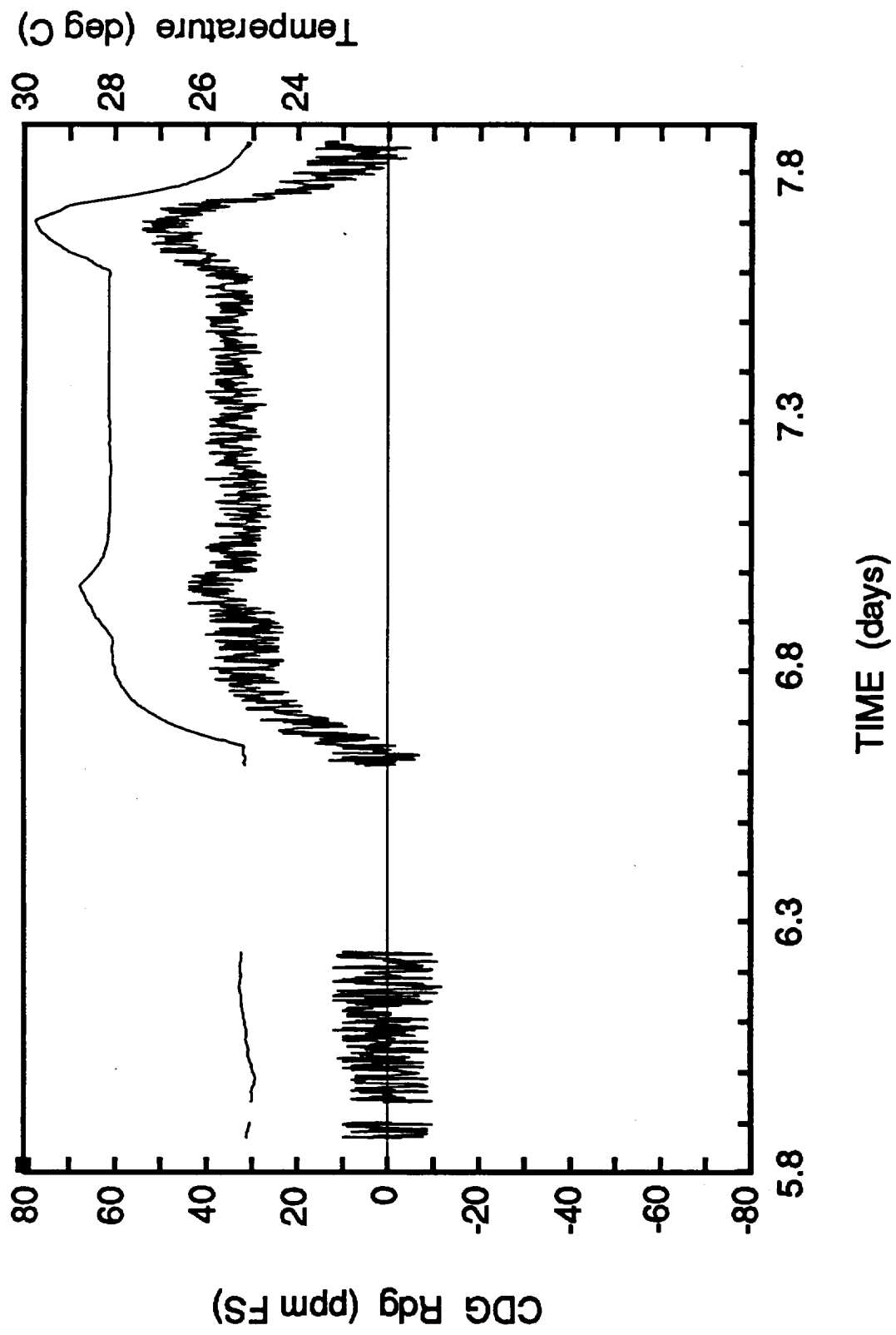
ZERO DRIFT during WARMUP of 1 Torr CDG #2



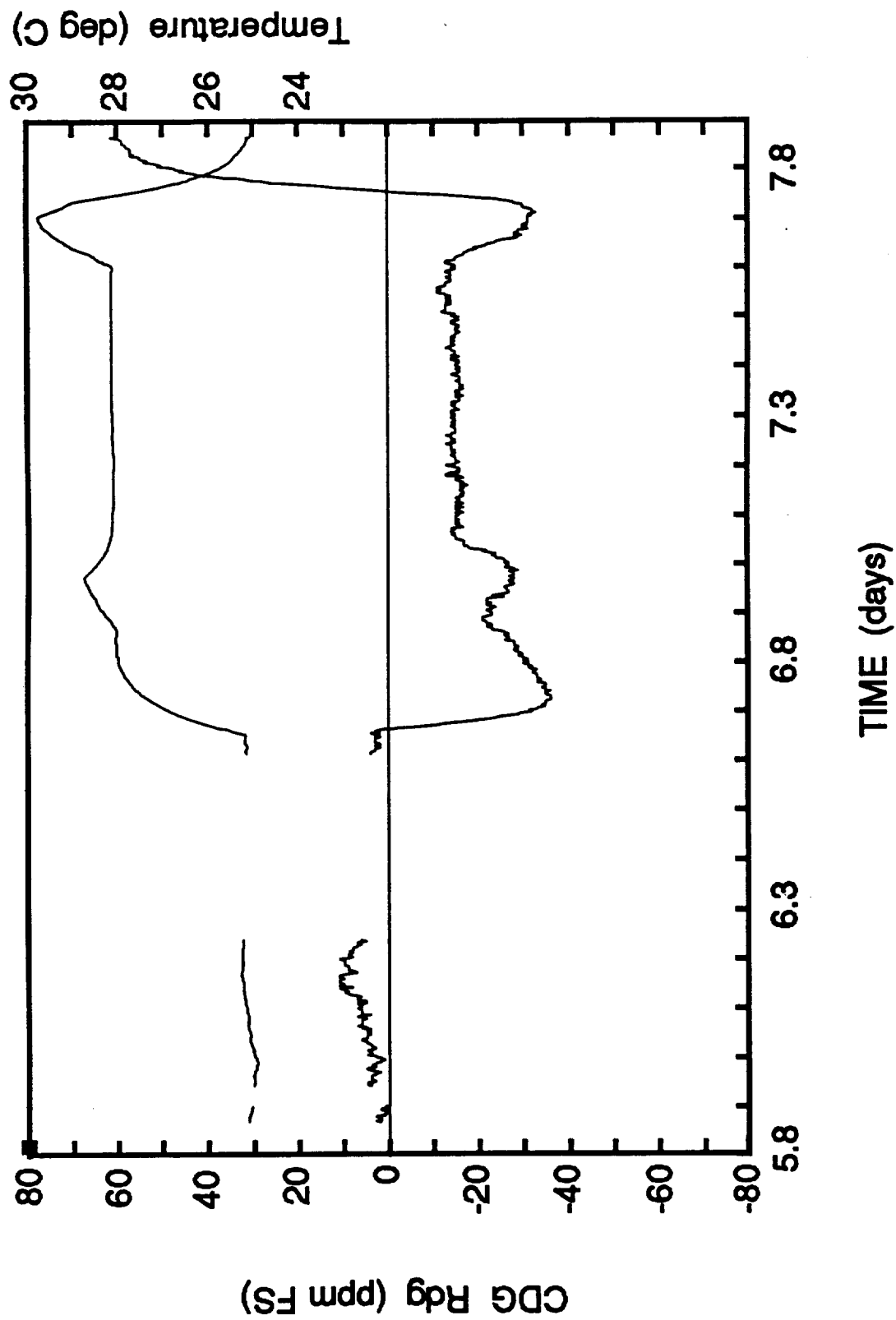
# TIME REQUIRED for CDG WARMUP



# ZERO INSTABILITY of 1 Torr CDG #2

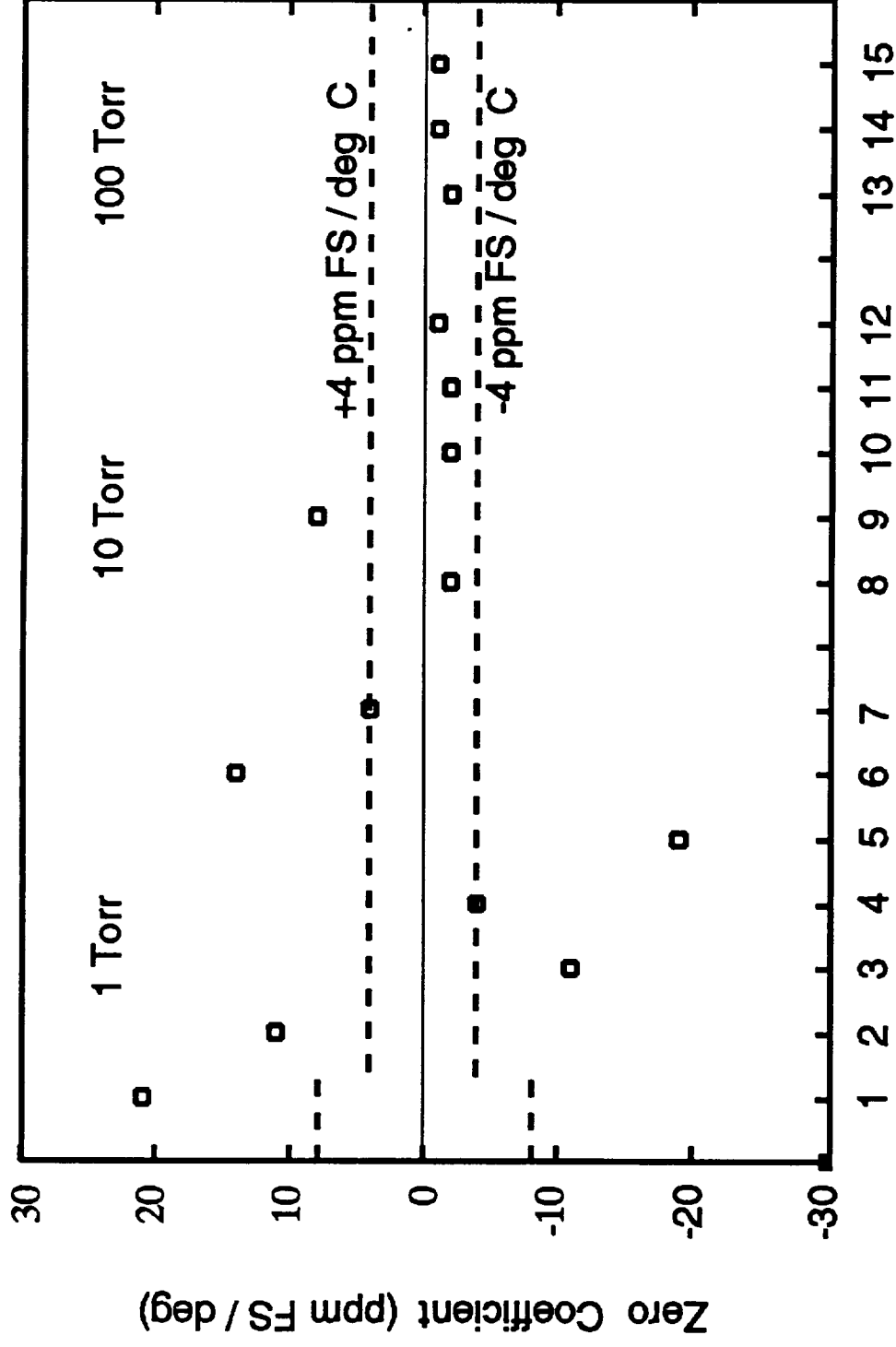


# ZERO INSTABILITY of 1 Torr CDG #5



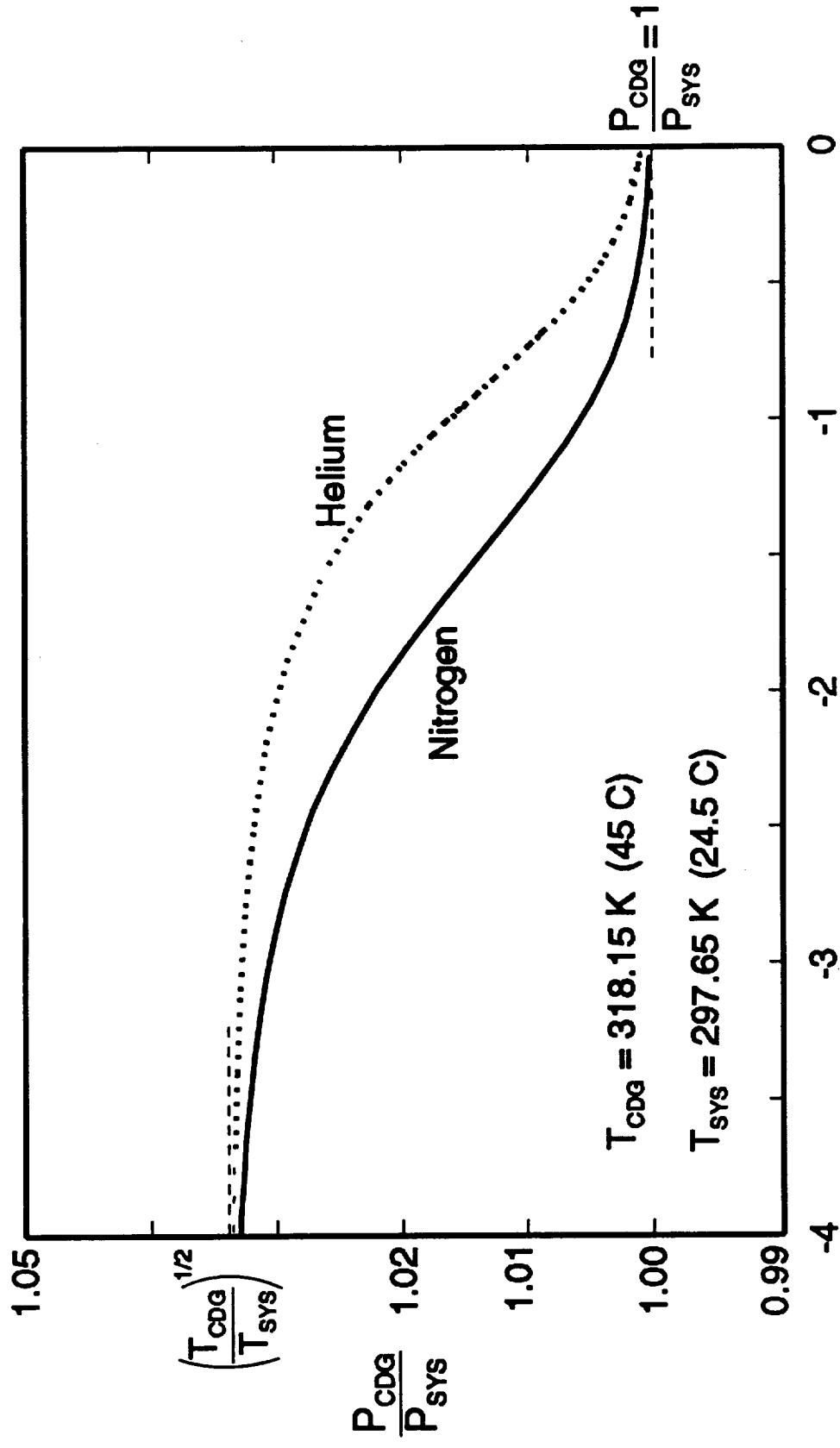


# ZERO TEMPERATURE COEFFICIENTS

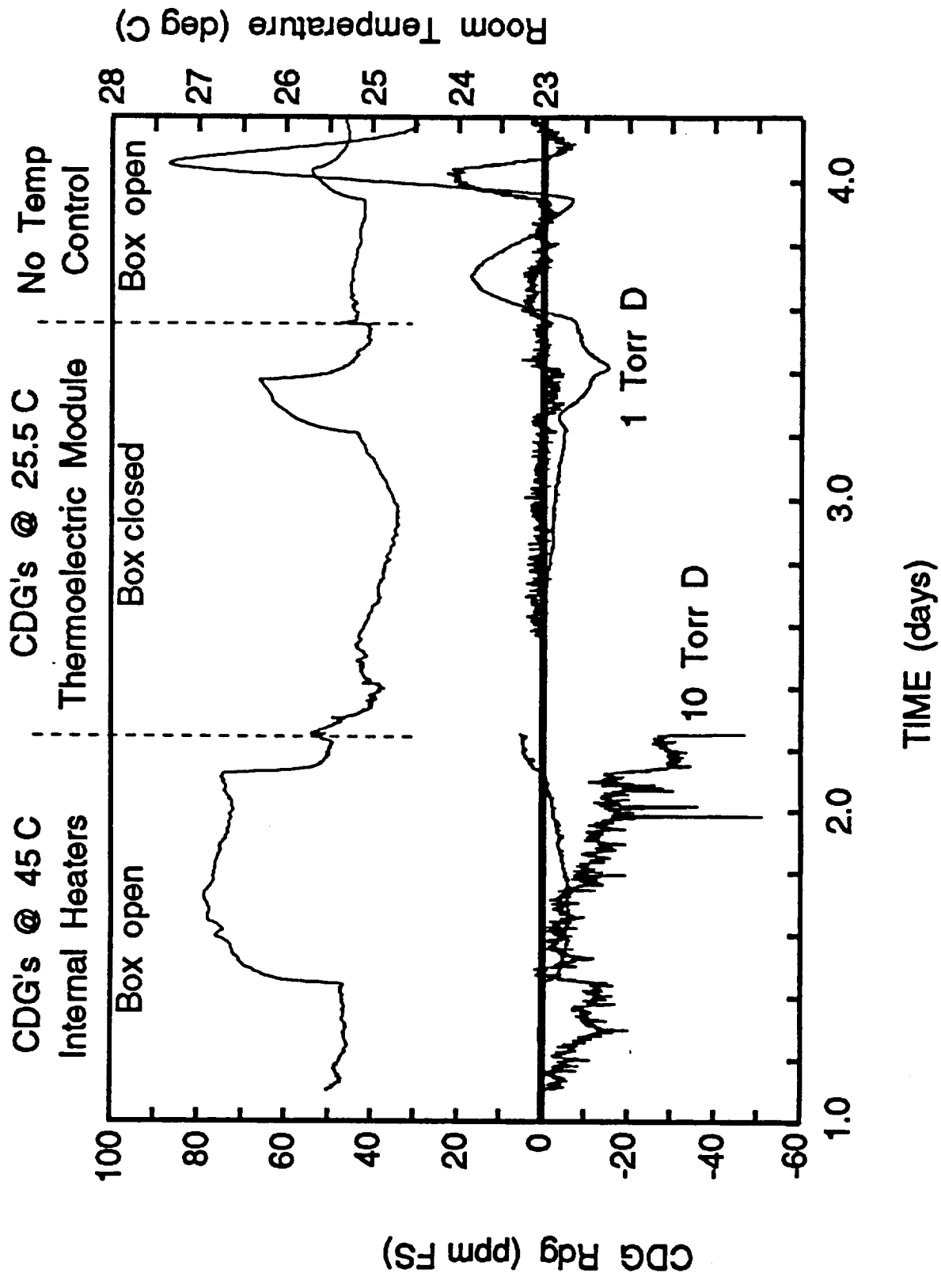


CDG ID Number

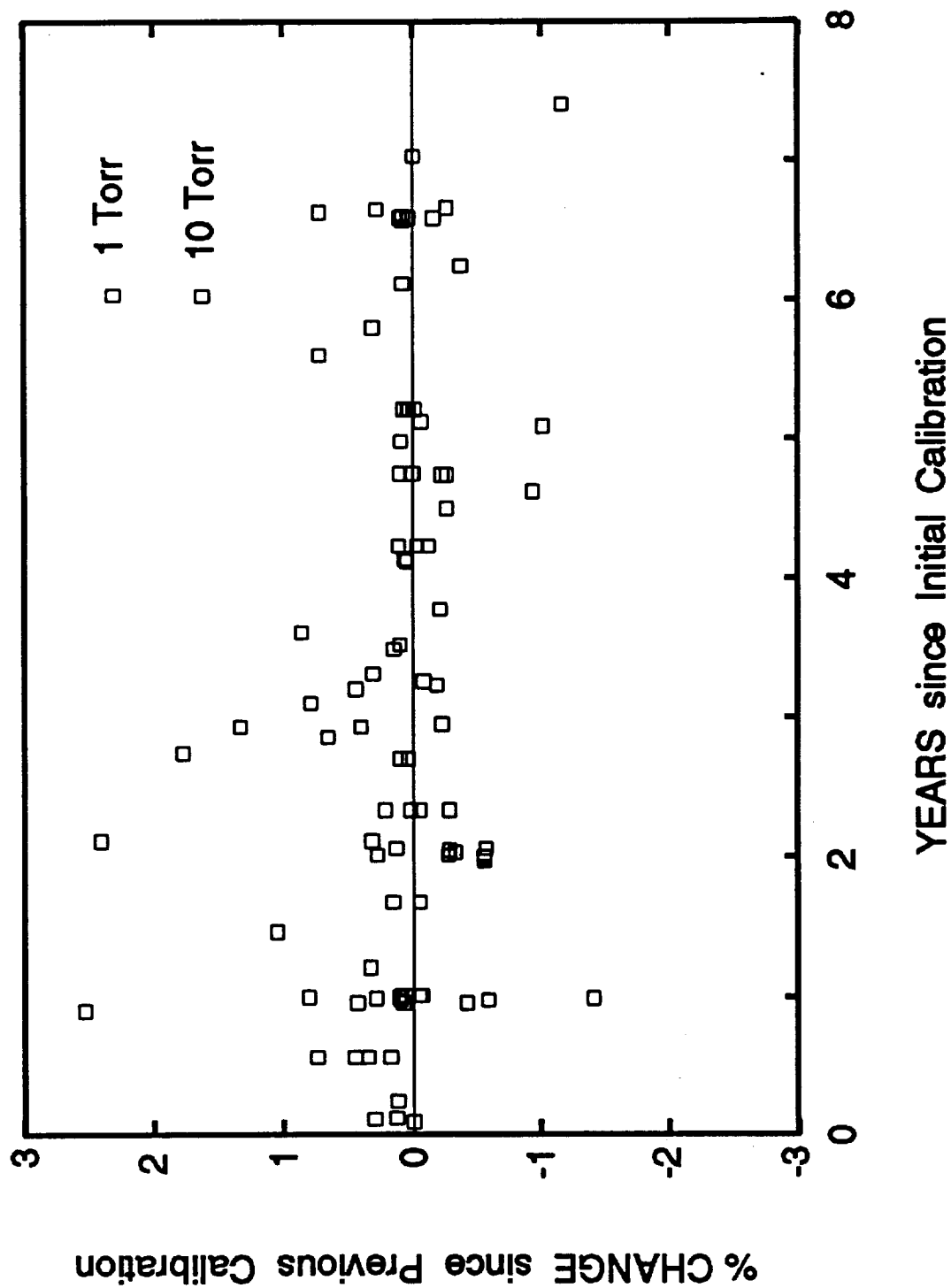
# THERMAL TRANSPIRATION EFFECT



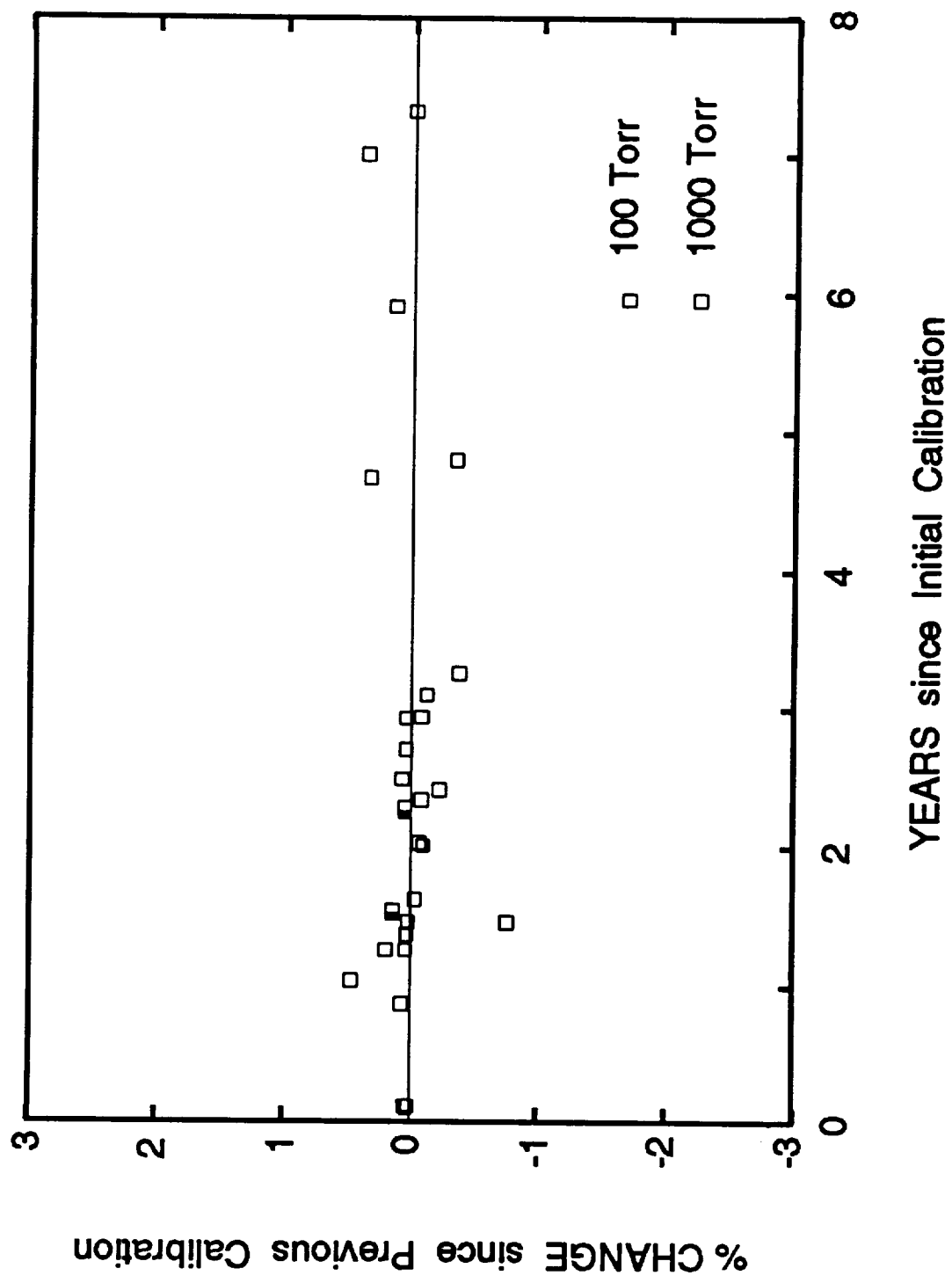
$\text{LOG}_{10}(P_{SYS} \text{ in Torr})$



# Check for CDG STABILIZATION with AGE



# Check for CDG STABILIZATION with AGE







## **RADIOMETRIC PHYSICS DIVISION**

National  
Institute of  
Standards and  
Technology

U.S. Department of Commerce

Gaithersburg, Maryland 20899

September 1991





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## **INTRODUCTION**

The Radiometric Physics Division (844) is the primary unit within NIST for carrying out the basic mission of promoting accurate and useful optical radiation measurements in the ultraviolet (uv), visible, and infrared (ir) spectral regions. The Division's activities seek to achieve three primary goals:

- To develop, improve, and maintain the national standards and measurement techniques for radiation thermometry, spectroradiometry, photometry, and spectrophotometry,
- To disseminate these standards by providing measurement services to customers requiring calibrations of the highest accuracy,
- To conduct fundamental and applied research to develop the scientific and technical basis for future measurement services.

The Division employs research scientists, engineers, technicians, and calibration specialists, and maintains a balanced mix of research, development, and measurement services. It is organized into four operational groups,

- Infrared Radiometry
- Detector Metrology
- Thermal Radiometry
- Spectrophotometry

and operates under a project structure with collaborations across group lines. The calibrations and related measurement services provided by the Division has been documented in a NIST Special Publication, SP-250, the NIST Calibration Services Guide which was published in 1989. This publication is described at the end of this brochure.

## **COLLABORATIONS**

In pursuing its goals, the Division is actively engaged in collaborative efforts with industry, other government agencies, universities, professional societies, and standards organizations. Its programs are developed in consultation with user groups at national and international levels.

### ***CORM***

The U. S. Council for Optical Radiation Measurements (CORM) is a paramount organization which aims at establishing a consensus among interested parties on industrial and academic requirements for physical standards, calibration services, and interlaboratory collaborations in the field of optical radiometry. In a 1989 report entitled "Pressing Problems and Projected National Needs in Optical Radiation Measurements," CORM has stated that the following radiometric and spectrophotometric projects should be undertaken on a priority basis:

- Improved Standards of Spectral Radiance and Irradiance
- Infrared Detector Standards
- Radiometry: Measurement Procedure and Technique
- Imaging Radiometry
- Long-Wave Infrared Radiometry
- Photometry: Improved Measurement Capability
- Pulsed Radiometry
- Laser-Beam Profile
- SRM's for:
  - ◆ Visible and Near-IR Reflectance Factor
  - ◆ IR Total Hemispherical Reflectance Factor
  - ◆ Visible and Near-IR BRDF
  - ◆ Visible High Transmission Density
  - ◆ Whiteness
- Documentary Standards of Geometric Conditions in Color Measurements

Some of these goals are being incorporated into the Division's planning for new program thrusts and initiatives. Other agency support for achieving the objectives is sought, and joint programs are created which benefit the radiometric community.

## *LTEC*

The Division participates in the activities of the Lamp Testing Engineers Conference (LTEC). The membership of LTEC is drawn from the lighting manufacturing industry and has as its goal the quality of testing and standards for illuminating sources. The Division's activities in photometry and spectroradiometry support a wide range of industrial and governmental measurement activities.

## *CIE, CCPR*

The Division is an active participant in international groups such as the International Commission on Illumination (CIE) and the Consultative Committee on Photometry and Radiometry (CCPR). These groups promote international intercomparison of fundamental measurements and seek cooperation in devising measurement definition and technology. As an example, the Division has been the lead laboratory in a CCPR-sponsored intercomparison of spectral irradiance, which has involved 13 national standardizing laboratories. These intercomparisons help ensure that the standards furnished to U. S. customers are consistent with the demands of world trade. The Division's staff maintain an active role in the committees of both the CIE and CCPR and participate in the planning of future intercomparisons and standards maintenance activities.

## *CCG*

A significant portion of the Division's activities is devoted to standards development and measurement support for other agencies. The Department of Defense has funded the development of major measurement facilities in the Division for low-background, infrared radiometry, thermal imaging, UV detector characterization, and bidirectional scattering metrology. Collaborations with the Calibration Coordination Group (CCG) of DoD continued during FY 1991 and will continue in FY 1992 with emphasis on the following tasks:

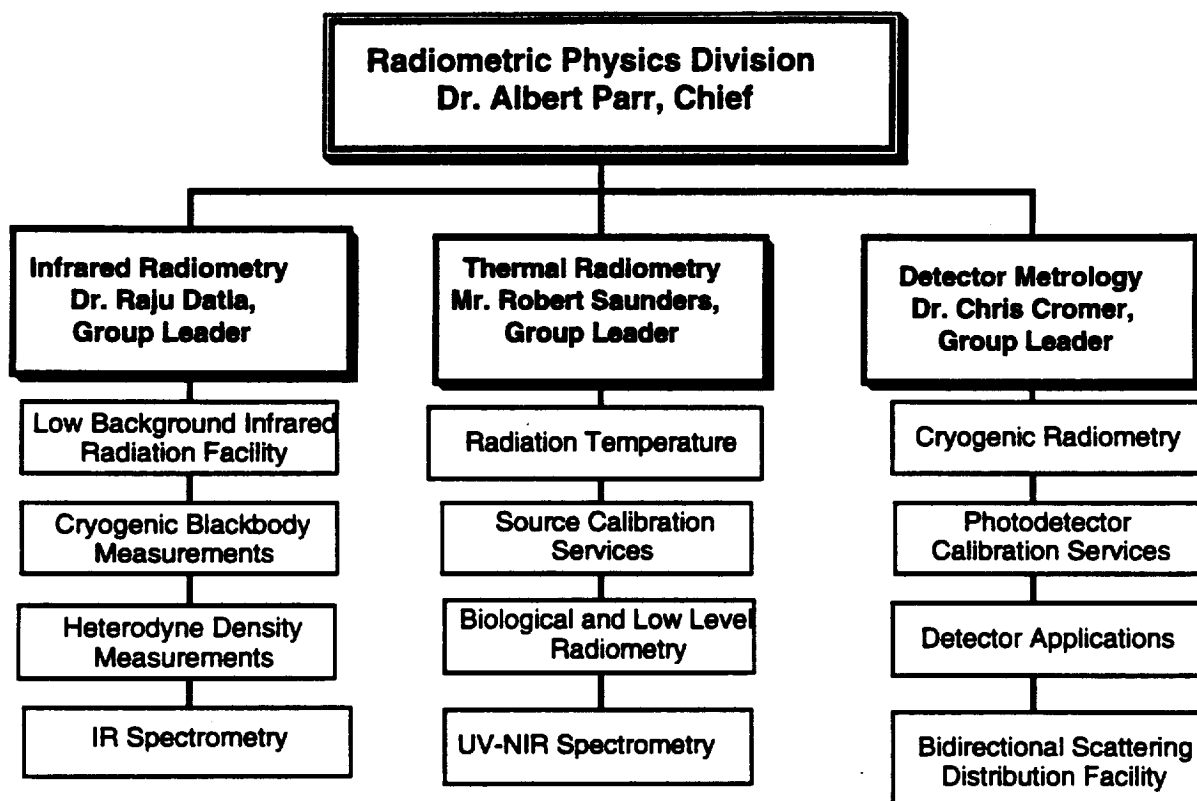
- Low-Background Infrared Standards
- Ultraviolet Radiometry
- Ambient-Background Infrared Detector Characterizations
- Photodetector Transfer Standards
- Bidirectional Reflectance of Optical Surfaces
- Long-Wavelength Infrared Spectrophotometry
- Thermal Imaging

## *Civilian Agencies*

The Division has provided measurement support to NASA and NOAA for space-borne radiometry, and is engaged in collaborations with EPA and NASA on terrestrial and extraterrestrial UV solar-irradiance measurements. It has also developed primary flammability standards for the FAA.

## **STAFF AND ORGANIZATION**

The Division presently employs 27 full time scientists and engineers and has from 6 to 8 full time guest scientists participating in the ongoing research and development activities of the Division. The Division is organized into three groups, each managed by a group leader reporting directly to the Division Chief. This organization is largely for administrative purposes with technical activities being carried out under a project structure within the various groups. The project structure allows for well defined technical activities to be accomplished with clear lines of responsibility for the staff involved. The project structure is flexible and can be adjusted to meet timely challenges in the Division's technical activities. This project structure is the composition of the projects detailed in the following section of this guide. The present organization of the Division is shown below.



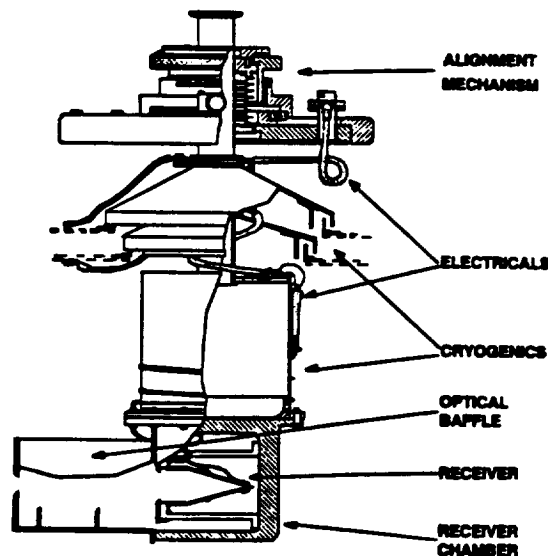
## **PROJECTS**

The project leader's name and phone number is given in the parenthesis. All phone numbers at NIST have the same prefix: 301-975, for simplicity only the last four digits of the phone numbers are listed.

### **Low Background Infrared Radiation (LBIR) Facility** (Raju Datla, 2131, and Steven Lorentz, 2311)

*Commitments:* Calibrate user-supplied blackbody sources and develop capability to characterize low background IR detectors and attenuators at the LBIR Facility. The LBIR employs its own ACR (Absolute Cryogenic Radiometer) as its primary detector. A prism-grating monochromator for LBIR spectral calibrations is being fabricated. New sources and detector characterization facilities are being designed and implemented. An instrument which can be directly used to calibrate focal plane array and sensor test facilities is being designed. This instrument will be calibrated at NIST and circulated to test facilities throughout the nation to help maintain calibration quality in the testing of IR sensors.

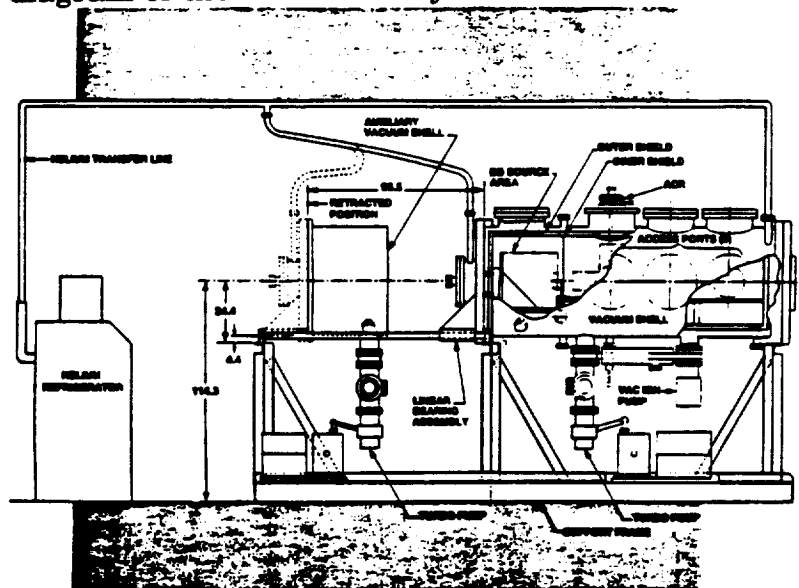
*Facility:* The LBIR Facility consists of a large (60 cm diameter by 152 cm long) vacuum chamber surrounded by a soft-wall cleanroom. A low background environment inside the chamber is achieved by cooling internal cryoshields to temperatures less than 20 K using a closed cycle helium refrigerator system. Sources of up to 30 cm square can be inserted into the chamber for calibration. A cross-section view of the ACR is shown.



## Cryogenic Blackbody Measurements (Steve Ebner, 2350)

**Commitments:** A low temperature blackbody is being fabricated at NIST for use in the LBIR Facility. The operating range of the source will be 100 K to 450 K and it features variable apertures and filters. The source will be used for detector calibration, optical materials characterization and serve for evaluation of the Absolute Cryogenic Radiometer in LBIR.

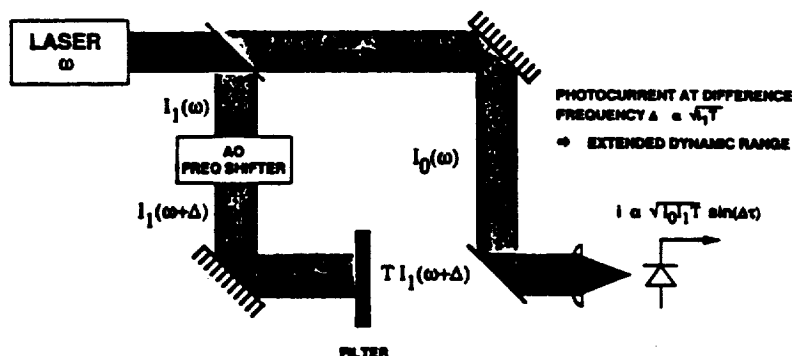
**Facility:** The blackbody will be housed in a vacuum shell of the LBIR. A diagram of the LBIR Facility is shown.



## Heterodyne Density Measurements (Alan Migdall, 2331)

**Commitments:** The laser heterodyne densitometry technique has been extended to the infrared. Measurements have been made at a dynamic range of 12 decades at 10.6 microns at room temperature. A new cryostat has been constructed to allow measurement of optical densities of materials at cryogenic temperatures.

**Facilities:** A transmission densitometer based upon laser heterodyne principals is used to measure transmission densities up to 12 at 633 nm and at 10.6  $\mu\text{m}$ . A diagram of the laser heterodyne set up is shown.



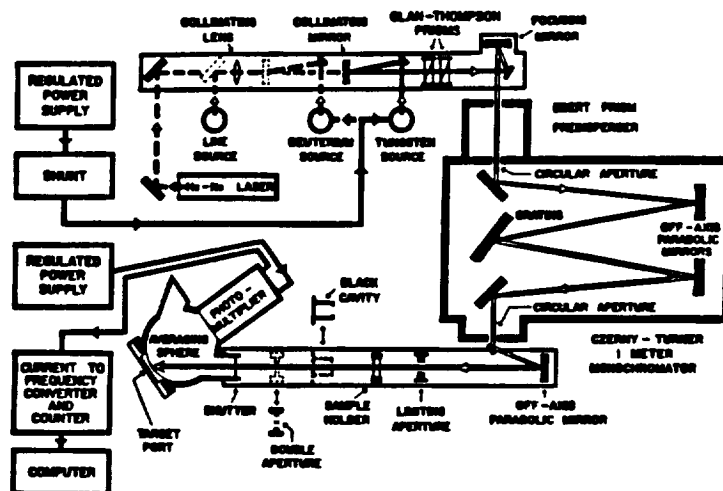


## UV-Visible-NIR Spectrophotometry

(Kenneth Eckerle, 2343)

**Commitments:** In the UV-visible-NIR spectral region, calibration of user-supplied filters and reflectance standards is available; transmittance, reflectance, and optical density standard reference materials are available, as well as the methodology for intrinsic standards such as pressed powdered PTFE. A measurement assurance program is offered which allows a laboratory to compare their measurements with NIST's, and thereby exhibit measurement quality and accuracy.

**Facilities:** Reference instruments for maintenance of scales of transmittance, reflectance, retro-reflectance, and optical density. Laboratory facilities for manufacture of reflectance standards. Transfer instruments to perform spectral transmittance, spectral reflectance, and wavelength measurements from 200 nm to 2500 nm. A diagram of the diffuse reflectance reference spectrophotometer is shown on the following page. A diagram of the UV-Visible transmittance reference spectrophotometer is shown.

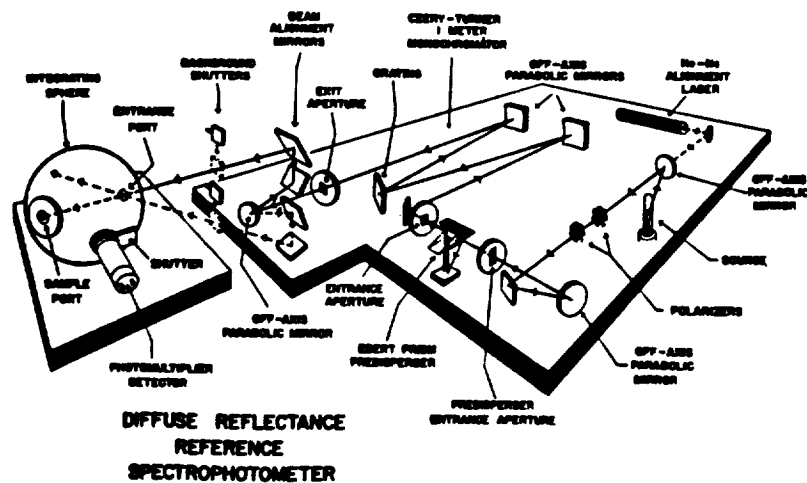


## IR Spectrophotometry

(Leonard Hanssen, 2344, and K. Eckerle)

**Commitments:** Calibration of user-supplied samples of spectral specular (regular) reflectance and transmittance in the IR will soon be available, as will wavelength standards for IR spectrometry. IR specular (regular) transmittance and reflectance, and diffuse reflectance standard reference materials are under development.

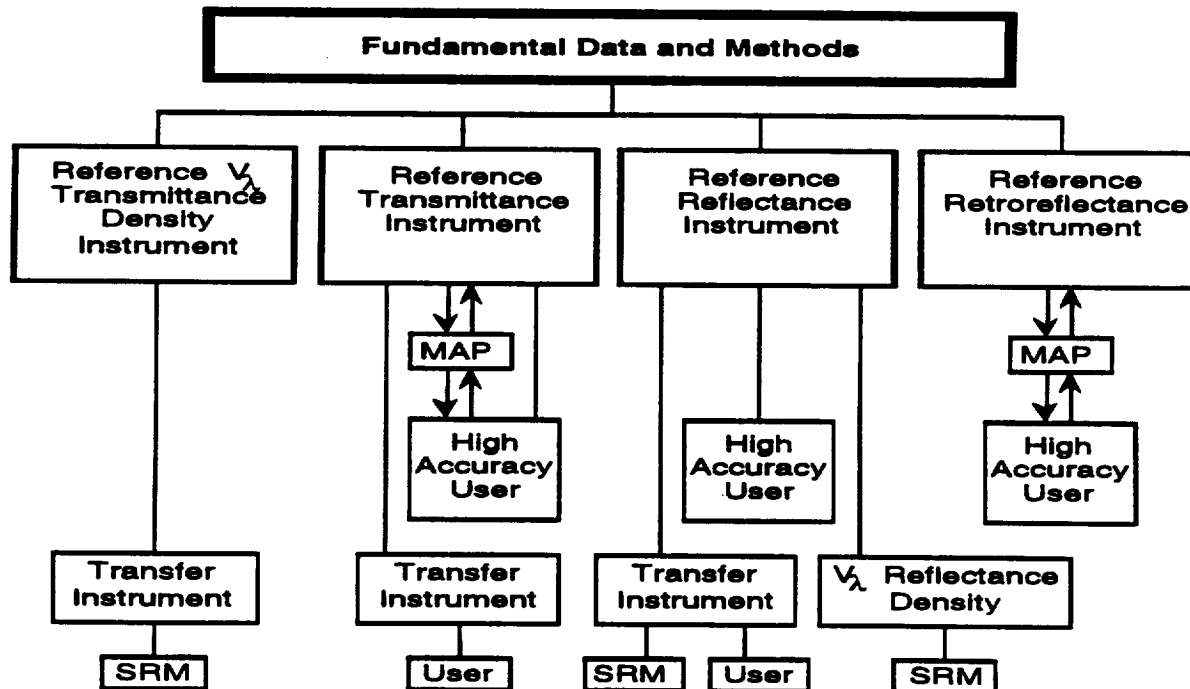
**Facilities:** Apparatus for IR specular reflectance and regular transmittance for the 2000 nm to 22  $\mu$ m region. Instruments for IR spectral diffuse reflectance, including a hemi-ellipsoidal collecting mirror and an integrating sphere are under design.



## Bidirectional Scattering Distribution Function (BSDF) (Clara Asmail, 2339)

**Commitments:** Methodology and equipment to measure the bidirectional reflectance and transmittance of optical samples are under development. These will be used to develop standard reference materials for use in calibrating BSDF instruments; intercomparisons will be arranged to insure measurement reliability among the various instruments used nationwide.

**Facilities:** A new instrument to measure the BSDF is being constructed in a clean room.



Dissemination of Spectrophotometric Scales

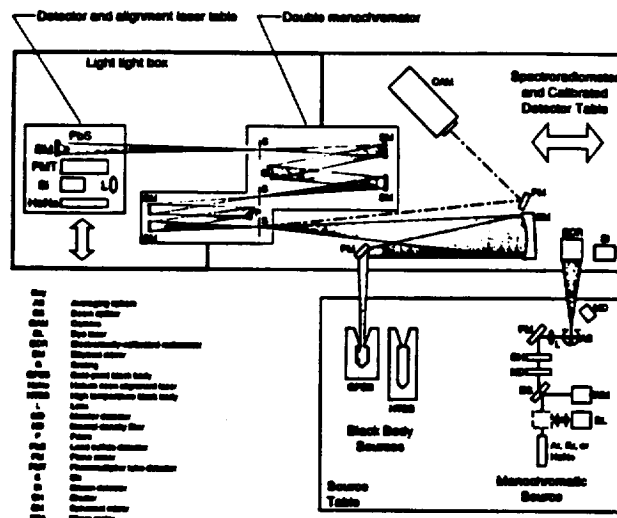
## Radiation Temperature

(Carol Johnson, 2322)

**Commitments:** Perform calibrations on user-supplied blackbody sources. Develop stable blackbody sources for other government laboratories. Develop the facility and methodology to characterize imaging devices for radiometric purposes. Provide research and development in the use of well characterized photodetectors to measure absolute temperatures of blackbody sources. Use the accuracy inherent in the HACR to improve radiation temperature measurements.

**Facilities:** Spectroradiometric freezing point laboratory used for radiometric determination of the temperature of the liquid to solid phase transition in metals. Thermal imaging laboratory devoted to developing calibration techniques for imaging devices. Ambient background blackbody calibration facility to operate in the temperature range of 0 to 3000° C. A drawing of the spectroradiometric temperature measurement facility is shown.

Spectroradiometric Temperature Measurements

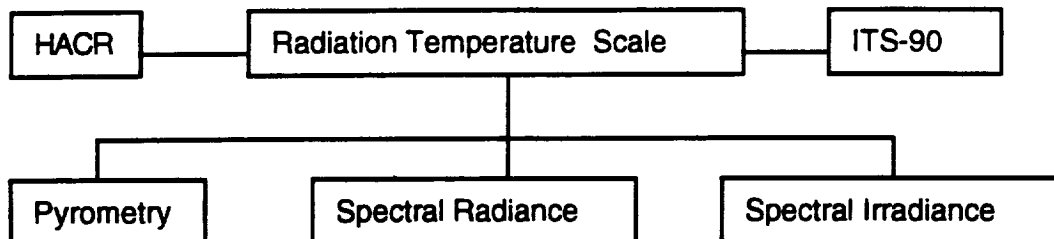


## Source Calibration Services

(Bob Saunders, 2355)

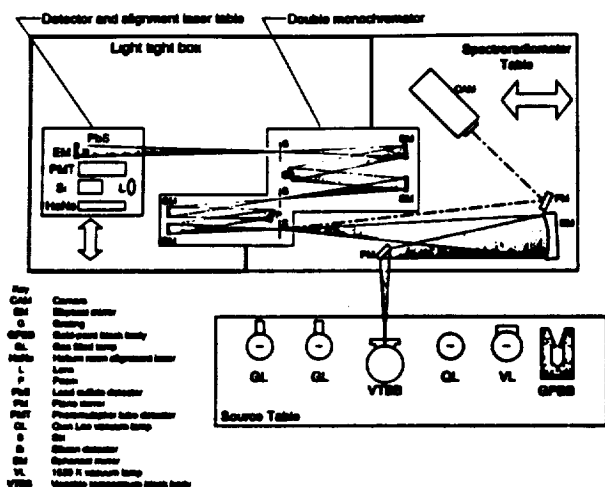
**Commitments:** Perform spectral radiometric measurement of irradiance and radiance standards in the spectral region of 200 to 2500 nm. Calibrate radiation temperature standards from 800 to 2500° C in the spectral region 400 to 1500 nm and calibrate user-supplied pyrometers. Perform and participate in international intercomparison to insure the maintenance of the US spectral irradiance and radiance scales. Provide consultation and assistance on instrument design and calibration to other government agencies for use in spectral radiance and irradiance measurements.

# SPECTRAL RADIOMETRIC SCALE REALIZATION

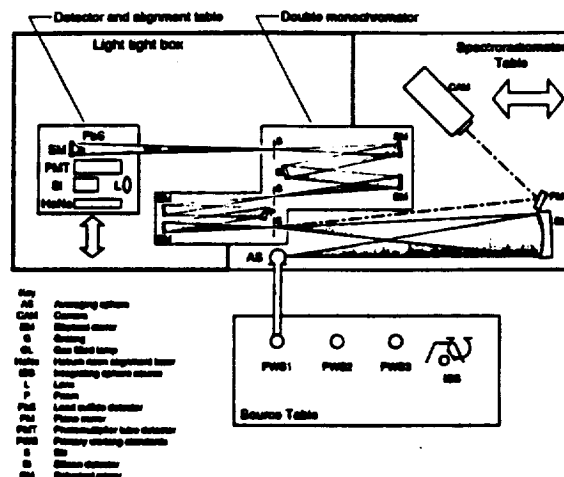


**Facilities:** Facility for Automated Spectral Radiometric Calibrations (FASCAL) accommodates both spectral radiance and spectral irradiance measurements. Diagrams of both setups for FASCAL and a diagram of the Optical Pyrometry Calibration Facility are shown.

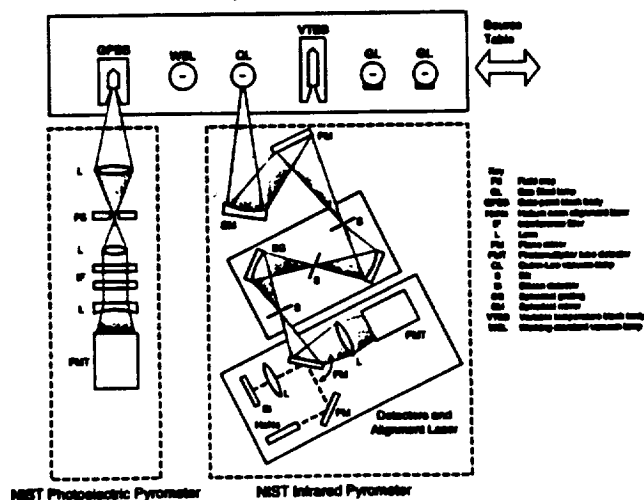
Facility for Automated Spectroradiometric CALibrations  
Spectral Radiance Measurements



Facility for Automated Spectroradiometric CALibrations  
Spectral Irradiance Measurements



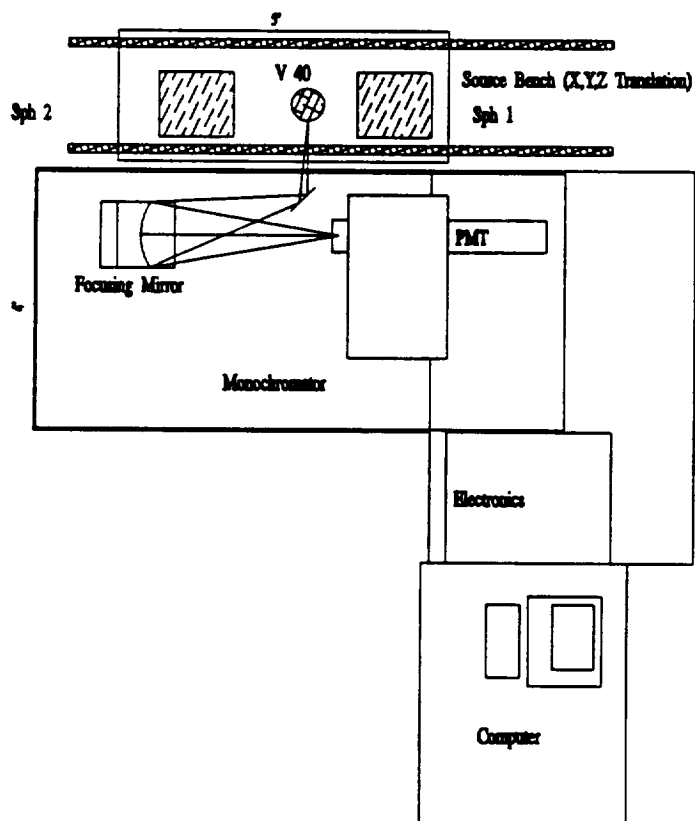
Pyrometry Calibration Facility  
Radiant Temperature Measurements



## Biological and Low Level Radiometry (Ambler Thompson, 2333)

**Commitments:** Provide standard reference luminescence samples and develop chemiluminescence standard reference materials. Develop low-level spectral radiance sources for calibrating sensitive detection systems. Calibrate variable output integrating sphere sources. Investigate beta-activated scintillation for the development of stable low light sources leading to the fabrication of single photon sources. Participate in the USDA program to arrange a network of UV-B measurement stations throughout the continental US. Perform terrestrial based solar UV measurements using a high accuracy resolution UV spectroradiometer. Develop a new automated beamconjoiner to measure detector linearity using DC measurement applications in the range of  $10^{-14}$  to  $10^{-4}$  amperes.

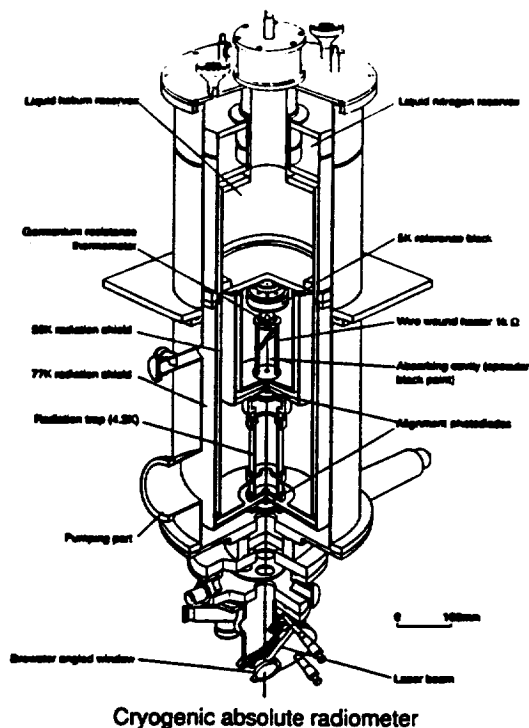
**Facilities:** Spectral Fluorescence measuring apparatus for the wavelength region 200 nm to 2000 nm. A spectroradiometer designed for low level spectral radiometric measurements in the low level radiometer lab is operational. Two automated radiometric linearity testers, beamconjoiners, are in use to provide tests for division needs and services for other organizations. The optical layout of the low level radiometry instrumentation is shown.



## **Cryogenic Radiometry**

(Jonathan Hardis, 2373)

*Commitments:* Commission the High Accuracy Cryogenic Radiometer (HACR), and employ it to improve the radiometric accuracy throughout the Division. The HACR will form the basis for many of the Division's calibration services. A diagram of the cryogenic absolute radiometer is shown.



*Facility:* The Absolute Cryogenic Radiometer alternately measures an intensity-stabilized laser light source and test detectors such as trap configuration silicon detectors which are used as transfer standards. The facility currently operates in the 200-1000 nm wavelengths and will be operating from 200 nm out to 10  $\mu$  in the near future.

## **Photodetector Calibration Services**

(Tom Larason, 2334)

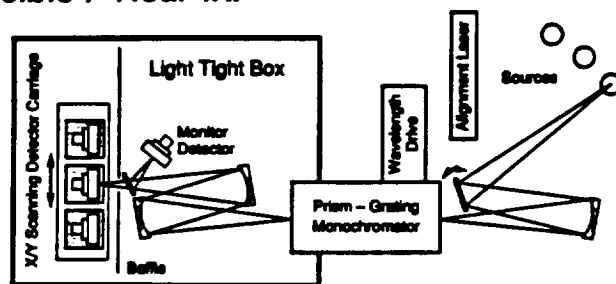
*Commitments:* Characterizations of absolute spectral response, spatial uniformity, and linearity of photodetectors for use in industrial and government labs are performed. Using a variety of detectors for working standards, the detector metrology calibration program has calibrated detector package rentals, calibrated silicon detector pair sales and provides special calibration on customer supplied detectors. The staff also

work closely with detector manufacturers and others at NIST to develop new measurement techniques and to formulate requirements for new optical detectors. This development effort will include the development of new transfer standard detectors which can take advantage of the high accuracy inherent in the absolute cryogenic radiometer.

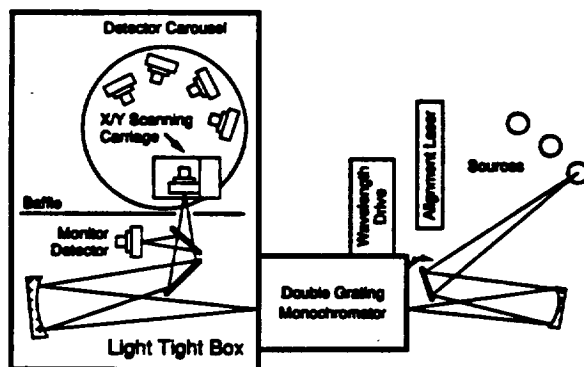
*Facilities:* Detector characterization laboratory for measuring wavelengths from 200 nanometers (nm) to 2000 nm and a new measurement facility for characterizing long wavelength infrared detectors is presently under development and construction. A drawing of the two spectral comparators, which make up the detector characterization lab, is shown.

## Spectral Comparators

Visible / Near IR:



UV:



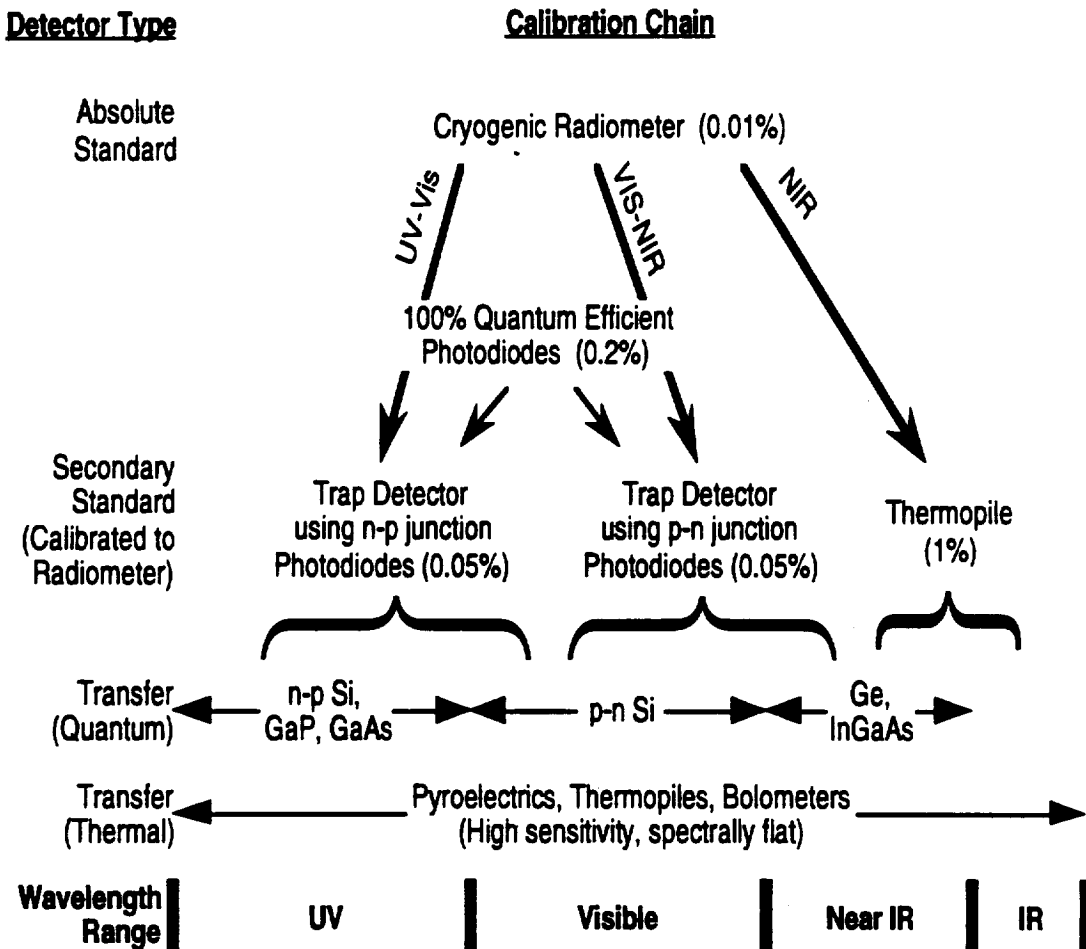
## **Detector Applications** (Chris Cromer, 3216)

*Commitments:* Development of detector packages with 14-decades of dynamic range, to provide increased reliability and sensitivity in a variety of optical measurement areas. The staff of this project work closely with the other detector project to provide the best measurement strategies available and to ascertain the measurement needs of the Division and its customers. This group maintains luminous intensity standards and

provides photometric calibration to government, industrial, and university laboratories.

**Facilities:** The Photometric calibration laboratory, and the Semiconductor device electronic characterization lab are used for Detector Applications Projects.

The Detector Metrology projects are working closely with the other projects to develop appropriate transfer standards with improved accuracy where absolute detectors are a part of the measurement chain. The chart below shows the planning of the integration of the improved accuracy afforded by the HACR into the spectral regions covered by radiometric services.







## **RESEARCH ACTIVITIES**

The Division maintains research and development activities in many areas of radiometry, photometry, and spectrophotometry. These efforts are directed toward improvements in measurement technology that benefits the nation's scientific and technical communities. These activities often involve several projects and require the cooperation of staff from various groups. A sample of these activities are described below. For a more complete description of the research activities, the annual technical report should be consulted.

### *Detectors*

A program to implement the advantage of absolute cryogenic radiometers into the measurement systems of the Division has been started. A sensitive cryogenic radiometer was developed for the LBIR calibration efforts and a high accuracy cryogenic radiometer is being developed to serve as the measurement base in the Division. These radiometers are a part of laboratory facilities which are equipped with associated instruments to gainfully exploit the advantages offered. The Division has a joint program with the Electromagnetic Technology Division to develop a novel superconducting bolometer, which promises much greater sensitivity than existing devices. There are programs to develop stable reference detectors and to design amplifier circuits to obtain maximum sensitivity from commercial detectors.

### *Radiation Temperature*

Techniques utilizing accurate absolute detectors to measure the temperature of blackbody sources have been developed. The temperature of freezing-point sources such as gold and silver has been determined. This information has contributed to the redefinition of the gold freezing-point and the adoption of a new international temperature scale, ITS-90. This work continues in an effort to improve the spectral radiance and irradiance measurement scale.

### *Advanced Radiometry*

Optical heterodyne techniques have been developed which allow the measurement of the transmission density of materials over 12 orders of magnitude. Applications to the study of reflection properties of materials and of the optical properties of material at cryogenic temperatures are being explored. The Division staff maintain an interest in areas of physics other than radiometry in an effort to broaden the technical base for radiometry and to ensure that opportunities for new ventures are recognized. To this end, there is an effort in the use of synchrotron radiation to study fundamental properties of atomic and molecular systems and an effort to develop expertise in highly excited atoms as possible radiometric tools.

## *Bidirectional Scattering Distributions*

New instruments are under development to develop techniques and SRM's required for Bidirectional Scattering and Reflectance Distribution Function (BSDF and BRDF) metrology. A class-10 clean room has been installed and the first instruments will be operational in 1991. This research program is driven by increased demands by industrial and government labs for much improved measurements of the quantities which characterize precision optical surfaces.

The multiple-angle BSDF reference system (MARS) is in the process of being constructed. It will have a fixed source system with shared use of an optical layout by various lasers and a rotating detector module. It will include full hemispherical coverage for both incident and viewing angles and will include laser wavelengths from the UV to the IR.

A study has been started to investigate the physical properties of materials required to produce high reflectance and/or near-perfect diffusing samples in the IR. A new candidate material which has many attractive properties, including low absorptance beyond 7  $\mu\text{m}$ , is diamond. Diamond films and particles can be grown by chemical vapor deposition at NIST. Black polished glass has been identified as a candidate material for low-level BRDF measurement standards.

## **CALIBRATION SERVICES**

The Division staff performs calibrations to support a wide range of radiometric, pyrometric, spectrophotometric, and photometric needs. These services and the staff members responsible for them are listed below. Information on the availability of service should be obtained from the associated staff member, directly.

### ***Photodetector Characterization***

Contact: Chris Cromer, 301-975-3216

### ***Photometric Measurements***

Contact: Jonathan Hardis, 301-975-2373

### ***Low Background Infrared***

Contact: Raju Datla, 301-975-2131

### ***Spectrophotometric Measurements***

Contact: P. Yvonne Barnes, 301-975-2345

### ***Pyrometry Calibration***

Contact: Charles Gibson, 301-975-2329

### ***Spectral Radiance and Irradiance Sources***

Contact: John Jackson, 301-975-2330

(Government staff may dial FTS-879- rather than commercial 301-975-)

Mail correspondence should be addressed to the appropriate staff member at the following address.

Staff Member  
NIST  
Radiometric Physics Division  
Metrology B306  
Gaithersburg, Maryland 20899

## **CALIBRATION PUBLICATIONS**

The following publications are available which describe the calibration activities of the Division:

NBS SP 250-1, Spectral Radiance Calibrations

NBS SP 250-6, Regular Spectral Transmittance

NBS SP 250-7, Radiance Temperature Calibrations

NBS SP 250-8, Spectral Reflectance

NBS SP 250-15, Photometric Calibrations

NBS SP 250-17, The NBS Photodetector Spectral Response Calibration Transfer Program

NBS SP 250-20, Spectral Irradiance Calibrations

NIST SP 250, NIST Calibration Service Users Guide 1989,  
(soon to be updated)

NIST SP 260, NIST Standard Reference Materials Catalog 1990-91

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# **COST-EFFECTIVE CALIBRATION THROUGH FORMAL TEST OPTIMIZATION TECHNIQUES**

**T. Michael Souders  
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National Institute of Standards and Technology**

**Gaithersburg, MD**

# **PURPOSE**

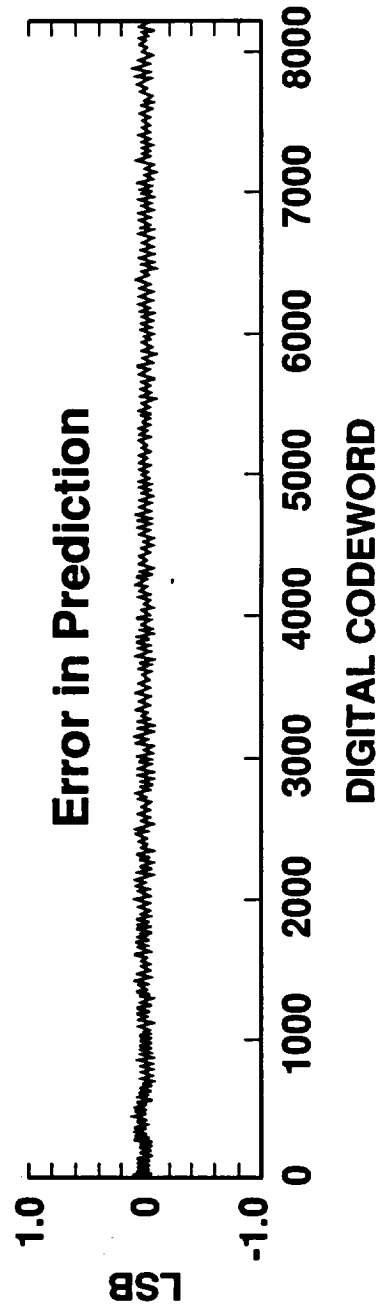
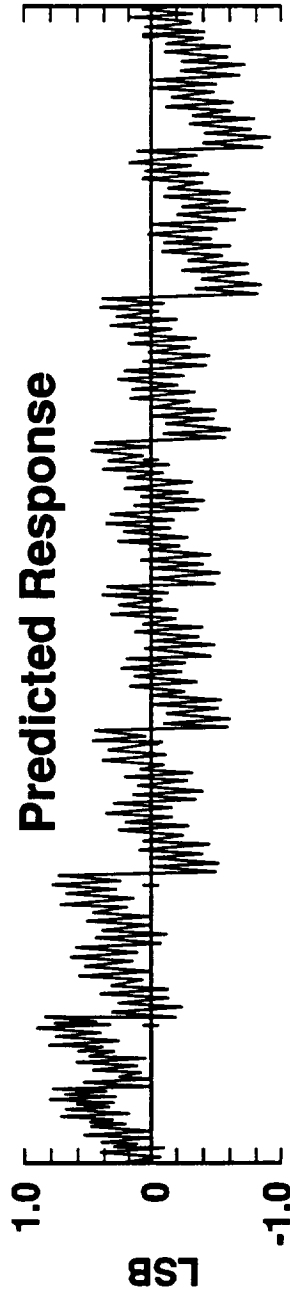
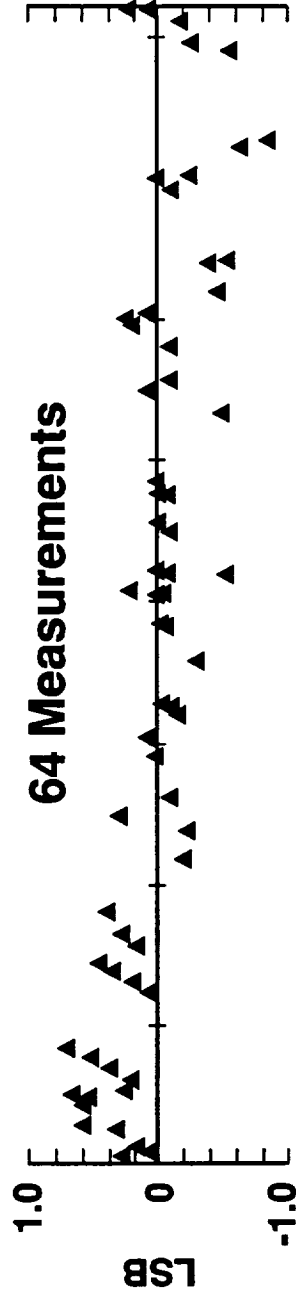
**To provide:**

- a comprehensive framework**
- analytical tools**

**for developing and implementing efficient tests for analog and mixed-signal devices**

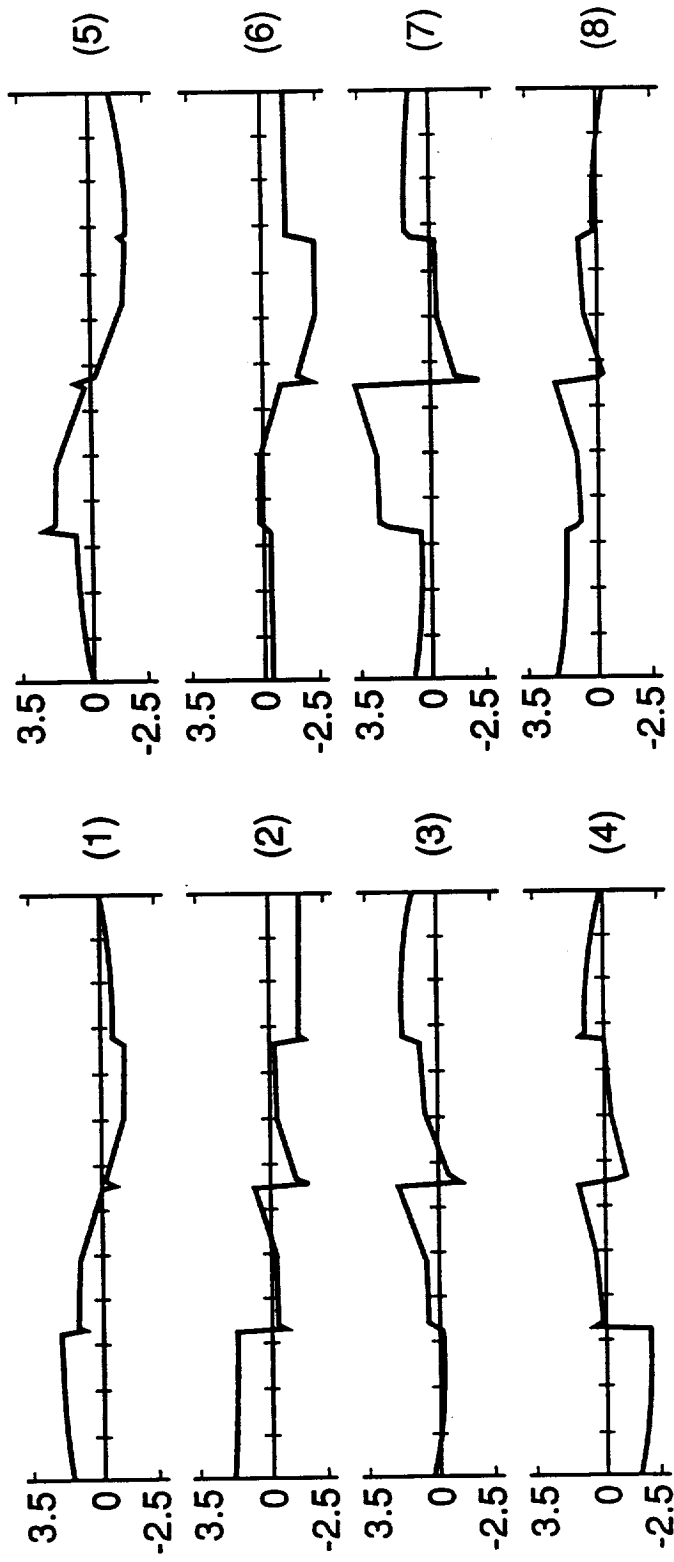


# INL TEST RESULTS (13-bit A/D CONVERTER)

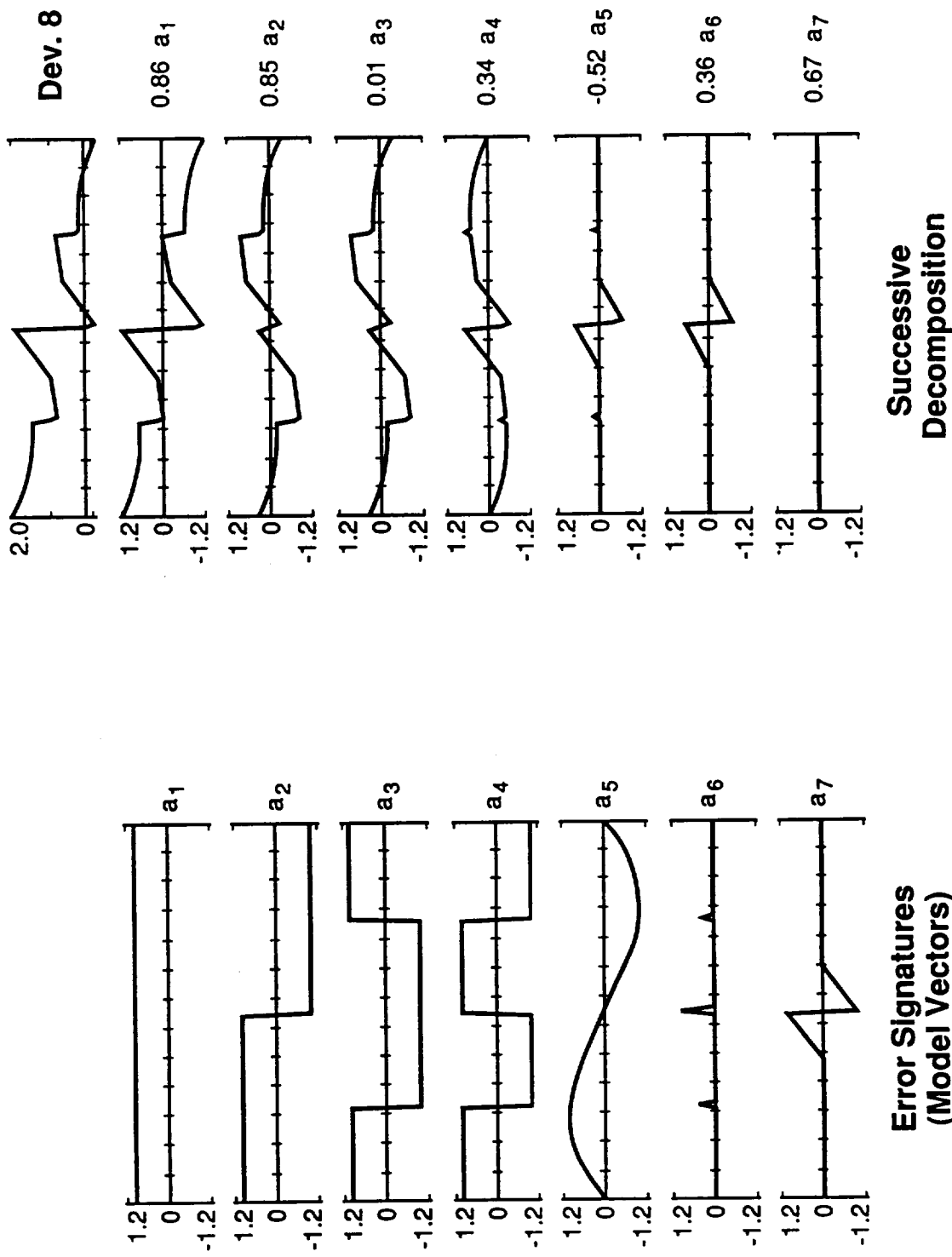


# RESPONSE ERRORS

## Eight Units of Hypothetical Device

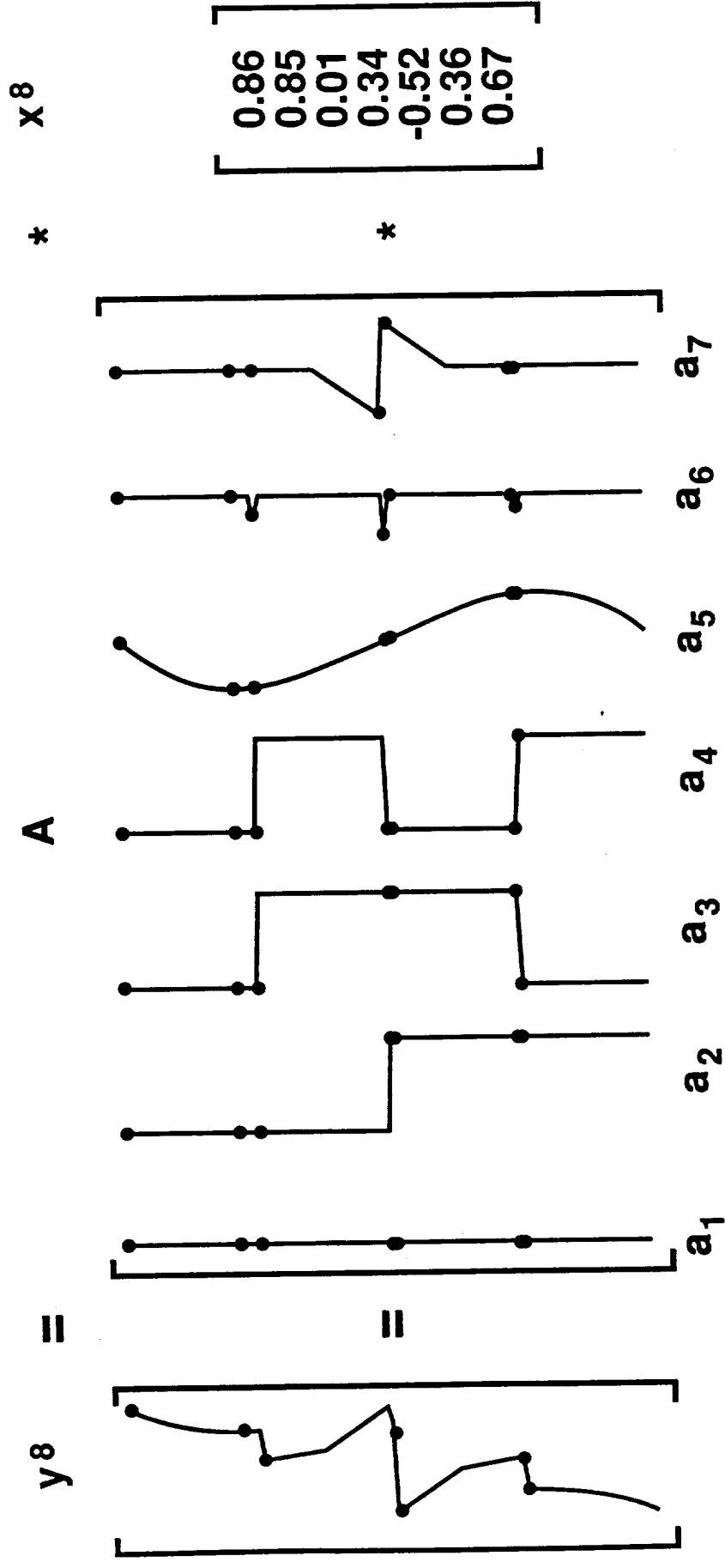


# DECOMPOSITION OF RESPONSE ERRORS



# MATHEMATICS (Framework)

- N variables requires N independent equations to solve
- Each equation requires a new measurement



# **APPROACH**

- **Develop Model**
- **Select Test Points**
- **Perform Test**
- **Predict Response**

# **TEST POINT SELECTION**

## **PROBLEM:**

Find "Best" set of  $N$  equations  
i.e., most independent set

## **SOLUTION:**

QR factorization

# **ADDITIONAL TEST POINTS**

- Adds redundancy to:
  - reduce errors caused by noise
  - detect and flag model errors
- Selected from calculation of prediction variance
- Requires least-squares solution

# MATHEMATICS (Equations)

(1) Error Model

$$y^k = A x^k$$

(2) Reduced Model after Test Point Selection (QRF)

$$\tilde{y}^k = \tilde{A} x^k$$

(3) Parameter Estimation

$$\hat{x}^k = A^{-1} \tilde{y}^k$$

(4) Residual Calculation

$$\varepsilon^k = \tilde{y}^k - \tilde{A} \hat{x}^k$$

(5) Response Prediction

$$\hat{y}^k = A \hat{x}^k$$

(6) Prediction Variance  
(add test points)

$$\sigma_p^2 / \sigma^2 = \text{diag} [ A ( \tilde{A}^T \tilde{A} )^{-1} A^T ]$$



# MODELING

- Physical
  - sensitivity matrix
  - from SPICE or other simulator
  - requires detailed knowledge
  - component deviations must be small
- *A priori*
  - subset (of complete set) of basis functions e.g., Walsh
  - requires *a priori* knowledge
- Empirical
  - learning-based
  - derived from measurements on representative units
  - efficient, complete
  - requires no a priori knowledge

# EMPIRICAL MODELING

1. Select statistically significant lot of k devices
2. Test all k devices at all m candidate test points
3. Form the matrix A':

$$A' = [ y^1 \ y^2 \ \dots \ y^k ] = \begin{bmatrix} y_1^1 & y_1^2 & \dots & y_1^k \\ y_2^1 & y_2^2 & \dots & y_2^k \\ \vdots & \vdots & & \vdots \\ y_m^1 & y_m^2 & \dots & y_m^k \end{bmatrix}$$

- A' forms a basis that spans the entire space of possible y vectors
- A' will almost certainly be rank deficient

**Weaknesses:** No direct correspondence between model variables and measurable physical parameters

**Model incorporates measurement noise**

## COLUMN PRUNING, CONT'

- (1) Perform Singular Value Decomposition on the Model Set,  $Y$ :

$$Y = U \Sigma V$$

- (2) Examine singular values in  $\Sigma$  matrix:

$$\Sigma = \begin{bmatrix} s_{11} & & & 0 \\ & \ddots & & \\ & & s_{tt} & \\ & & & 0 \end{bmatrix}$$

- (3) Select the first  $j$  columns of  $U$ , such that

$$\sum_{j+1}^t s_{ii}^2 \leq \sigma_m^2 \quad \sigma_m = \text{meas. noise}$$

# TESTING COMPLETENESS

- Measured by the accuracy with which a model describes the manufactured devices
- Requires a second, validation set of tested devices
- Procedure:

- fit model to test data of validation set:

$$\hat{x}^k = (A^t A)^{-1} A^t y^k$$

- Compute residuals of fit:

$r^k = y^k - A \hat{x}^k$  for all  $k$  in validation set

- Examine distribution of  $\|r^k\|$  vs.  $k$

## **EXAMPLE**

**Fluke Thermal Transfer Standard**

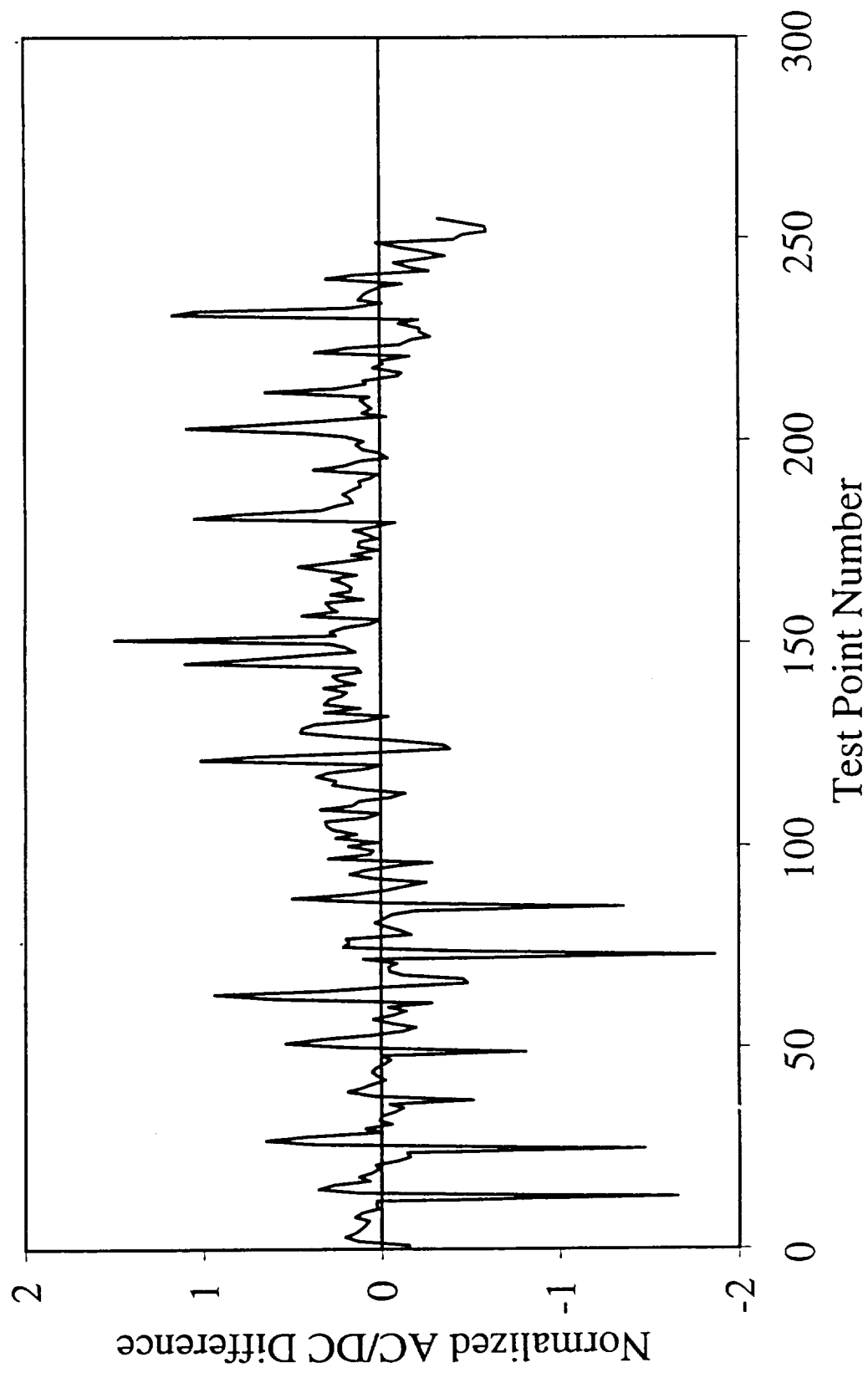
- **Multirange Instrument**
- **Expensive Calibration Support**
- **255 Candidate Test Points**
  - 9 ranges
  - 12 frequencies
  - 2 to 3 amplitudes

# **THERMAL TRANSFER STANDARD EXAMPLE**

## **EMPIRICAL MODELING**

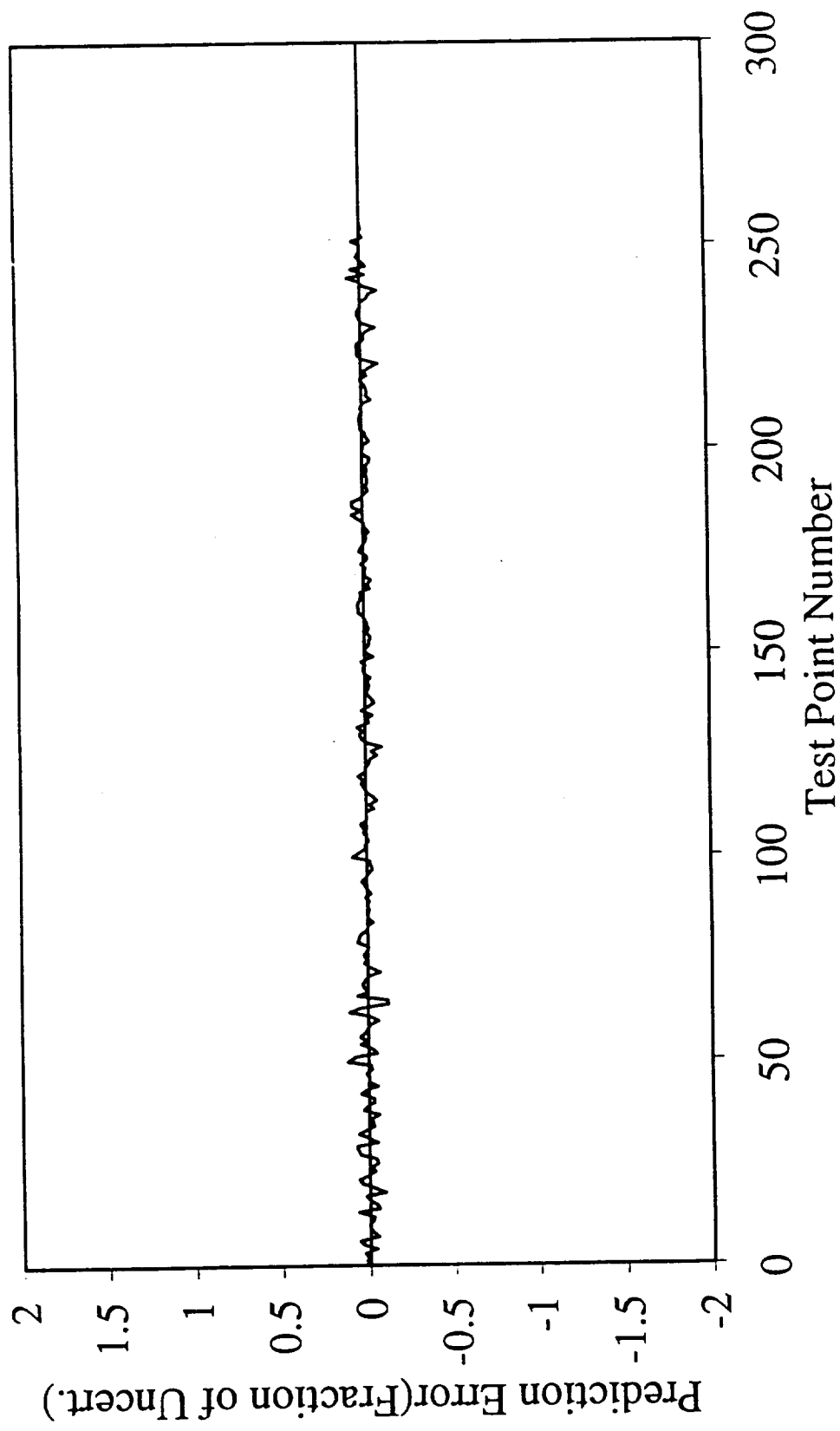
- Test Data from Manufacturer
  - complete test data (255 points each)
  - 139 instruments
  - different lots, different dates
- Divided into two Groups
  - 100 for modeling, 39 for validation
- Data Normalized by Manufacturer's Uncertainty Specifications
- Model: 20 parameters, 50 test points

# NORMALIZED DATA



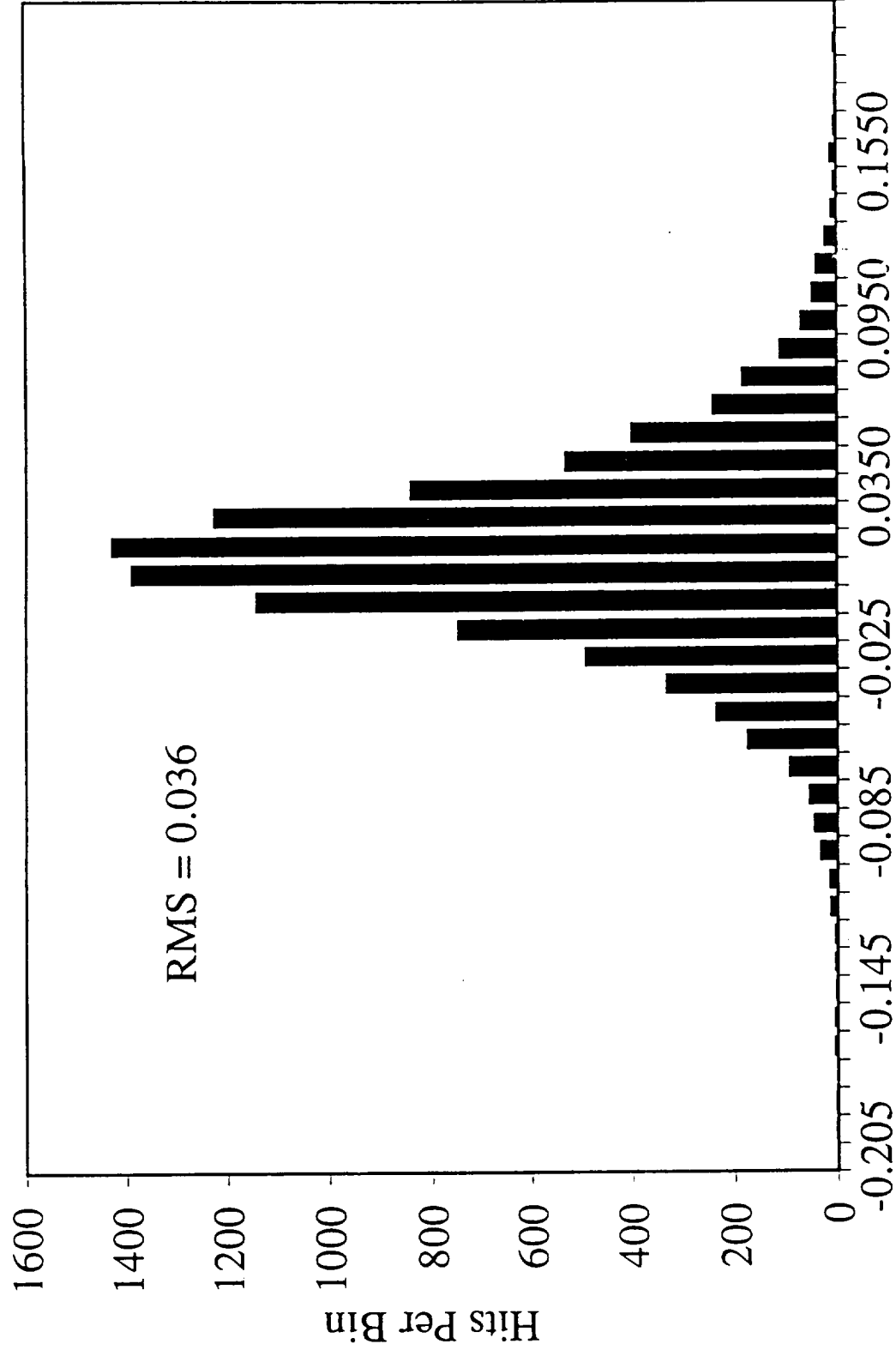
# TYPICAL PREDICTION ERRORS

(From Validation Set)





# HISTOGRAM OF PREDICTION ERRORS



## **OPPORTUNITIES FOR CALIBRATION LABS**

- Empirical Models from Records of Calibration History
- Adaptive Minimization of Test Costs Throughout Instrument's Life Cycle
- Enhanced Trimming and Alignment

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# CONCLUSIONS

- Analytical framework for
  - modeling error behavior
  - selecting test points
  - predicting global response
- Advantages:
  - reduces test time
  - applicable to wide variety of devices
  - can aid in trimming/alignment
- Problems
  - computationally intensive for very large problems
  - efficiency is limited for highly nonlinear responses



# TECHNICAL PRESENTATIONS



# **MOBILE CALIBRATION SYSTEM FOR GENERAL PURPOSE TEST INSTRUMENTS**

**BY**

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**FOR**

**LANGLEY RESEARCH CENTER**

## **ABSTRACT**

This paper provides a general discussion of mobile calibration systems that are being operated at NASA's Langley Research Center (LaRC). Emphasis is placed on a recently introduced system called the Field Instrumentation Calibration System (FICS), and on the details of its construction and operation. The paper describes procedural methods, system hardware and software, and the impact of mobile systems on calibration time and cost. The paper concludes with a brief discussion of planned enhancements and additional applications which are under consideration for LaRC's mobile calibration systems.

## INTRODUCTION

We have all witnessed the evolution of personal computers and their impact in the metrology workplace. Software is friendlier and more diverse. Electrical standards are becoming smaller and more versatile. Manufacturers of calibration standards are emphasizing automation capabilities so the equipment can be easily interfaced with computers. Without an extensive staff, a metrology lab can now develop a significant calibration station that can be transported to an instrumentation user's workplace.

LaRC has operated a mobile calibration system, Field Electronic Laboratory Instrument Calibration System (FELICS), an evolution of manual and automated techniques, for more than ten years. FELICS is structured around the Navy's proprietary Mecca design. This system uses Fluke 1722A/AP controller and Fluke 7411 software to control the source values and the sequence of events for the calibration process. Although it is highly productive, this system lacks the accuracy and operational advantages of current automation technology. At LaRC and Wyle Laboratories, recent developments in process and control automation have been primarily based on the utilization of personal computers. These developments were not practically transferable to FELICS.

In response to equipment user requests and suggestions for increased on site calibration support, the Instrument Research Division at LaRC developed a second mobile calibration system, the Field Instrumentation Calibration System (FICS). Procedures were simplified, and calibration capability was expanded in this PC-based, advanced calibration system. Incorporated in two portable cases were calibration standards, a personal computer and operating software, more than 500 calibration procedures, and requisite interfaces to address LaRC's spectrum of electrical instruments. Mobile calibration system coordinators and operators were given an increased decision-making role in meeting the technical needs of equipment users.

## PURPOSE AND OBJECTIVES OF A MOBILE CALIBRATION SYSTEM

LHB 5330.9 establishes an LaRC requirement for periodic calibration of electrical and electronic test and measurement instruments. This document also defines the structure and measurement criteria of LaRC's instrument calibration program. In support of this metrology program, the Instrument Research Division has developed two mobile calibration systems (FICS and FELICS) with a primary purpose of providing on site verification of the operational integrity and accuracy of test, measurement and diagnostic instrumentation. Moreover, the fundamental objective of mobile system operations is to satisfy the technical specification for calibration services with minimum impact on the instrumentation user's research activities and schedules.

LaRC's mobile calibration systems operate in full compliance with the following requirements for metrology services: (1) all standards used must be traceable to NIST or a natural constant, (2) calibration procedures and data must be documented and approved, (3) out-of-tolerance conditions must be documented and reported, and (4) uncertainty ratios and environmental conditions must be maintained and documented.



FICS is a state-of-the-art calibration station, a product of today's technology. Recent improvements in the reliability and ruggedness of laboratory calibration standards make them usable to perform extremely accurate field calibrations. Advances with personal computer hardware and software have led to the availability of very powerful, yet easily transportable, control and computation systems. FICS' combination of accurate, reliable field standards and computer-controlled processes ensure consistent compliance with LaRC's metrology program requirements for documented calibrations and data analysis.

### 3.0

## MOBILE CALIBRATION SYSTEM OPERATIONS

### 3.1 Deployment and Operations Procedures

A flexible schedule for mobile cart deployment to LaRC research facilities is generated to coincide, if possible, with annual maintenance of other facility equipment. Prior to the deployment of the mobile calibration system to a facility, Wyle's supervisor of the mobile cart service interfaces with the Instrument Coordinator and Technical Monitor, and with the facility coordinator to verify proposed dates for servicing instrumentation. The supervisor and facility coordinator jointly identify a proposed location of the mobile system within the facility during on site calibration operations. From the NASA Metrology Information System, the Center's Instrument Control Unit (ICU) produces a list of the facility's instrumentation which is recalled for calibration. The Technical Monitor and Wyle supervisor review the list for special handling or unusual calibration requirements. The supervisor confirms the service schedule and system location with the Technical Monitor. Notices of the impending service are posted in the facility to maximize user awareness and utilization of the on-site calibration process. The Technical Monitor arranges to have the mobile system transported to the facility at the appropriate time. The supervisor prepares, and the Technical Monitor approves Instrument Work Orders (IWO) for all instruments which will be serviced by the mobile calibration system.

After the mobile system is deployed in the facility, the calibration technician contacts individual users to obtain their equipment. Instrument calibrations are normally arranged to minimize interference with the daily activity of the facility or user. The Wyle technician operates FELICS and FICS with total emphasis on the customer's needs. He may assist the user in removing equipment from racks or other installations. The technician follows approved (mostly automated) procedures to calibrate and make the equipment available for use within hours. After completing an instrument calibration, the technician processes the applicable IWO, attaches any applicable calibration data, and forwards the documentation to the supervisor for review and entry into the metrology information system. If the need is critical, the calibration technician reinstalls and interconnects the instrument in the user's system. If the unit under test fails to meet operating specifications, the technician informs the user and the Wyle supervisor before taking corrective action.

### 3.2 Typical Instruments Calibrated by FICS & FELICS

Instruments which are typically calibrated by LaRC's mobile calibration systems are stand-alone, dedicated instruments, such as a Fluke 8840 DMM or HP 5334 counter. Presently, FELICS and FICS supports calibration of electrical and electronic instruments such as:

VOLTMETERS  
MULTIMETERS  
TEMPERATURE INDICATORS  
FUNCTION GENERATORS  
POWER SUPPLIES  
SIGNAL CONDITIONERS  
DECADE RESISTORS

CURRENT METERS  
OSCILLOSCOPES  
SIGNAL GENERATORS  
COUNTERS  
PANEL METERS  
AMPLIFIERS

### 3.3 Calibration Procedures

At the heart of LaRC's mobile calibration systems are the computers which control calibration operations. In the case of FICS, an IBM-compatible, 386 personal computer with dual IEEE-488 ports is used for process control, data analysis and calibration documentation. Fluke's MET/CAL software is used to develop and execute the majority of calibration procedures performed with FICS. Other FICS calibrations use the instrument manufacturer's recommended procedure which is normally provided in the service manual.

MET/CAL procedures contain detailed instructions for proper performance of the calibration process. The procedures are stored on the computer hard drive, and are called as needed by the calibration technician.

Attachment A is a printout of a typical MET/CAL-generated procedure for calibration of a digital multimeter. This procedure produces requisite calibration data and reports which are printed at the mobile workstation. A detailed description of FICS' MET/CAL software is presented in Section 5.0 of this paper.

## 4.0 FICS HARDWARE

FICS is housed in two transport cases with casters. The cases open to reveal a self-contained, metrology workstation. Each case contains two standard 19-inch, vertical equipment racks. Storage drawers are installed in the bottom areas of the racks. When closed and secured for transportation, each case is 72-inches high, 60-inches wide, and 30-inches deep. With these dimensions, the cases can be rolled through most doorways.

Each transport case is equipped with a line-power jack and operates on standard 120 VAC. Power conditioners (one in each case) filter and regulate the line power to calibration standards.

Each rack (two per case) contains cooling fans which provide filtered air to dissipate heat generated by electrical equipment.

The heart of FICS is an industrial grade, rack-mounted, 386-based personal computer. The computer is equipped with a 100 MByte hard drive, 1.44 MByte 3.5-inch floppy drive, and two IEEE-488 buss-control cards. One IEEE-488 card controls and polls the standards. The other control card is reserved for UUT use. The computer system also contains a VGA Monitor, IBM-style keyboard, mouse, and 24-pin dot matrix printer.

The use of a personal computer renders a very flexible and expandable data acquisition system. The command processor is MS Dos 5.0. Therefore, many software options are available. The calibration technician can load and run a variety of applications programs, such as a word processor, spreadsheet, and data base for generation of reports or a library of instrument specifications. Physical storage space is limited in FICS, and the computer is very valuable as an information file cabinet.

FICS contains the following calibration standards:

**HP 3458 Digital Multimeter:** This high-accuracy multimeter provides measurement of various UUT outputs and parameters, including dB measurement. Typical instruments calibrated with this standard include voltage sources, current sources, and power supplies.

**Fluke 5700A Multifunction Calibrator:** This is primarily a meter calibrator with DCV, ACV, DCA, ACA, 4 and 2 wire ohms, and dBm outputs. Used in conjunction with a Fluke 5725A Amplifier, this standard can generate current up to 10 amps and 1100 volts. It is also used to provide reference signals for calibrations of amplifiers, signal conditioners, and electronic filters.

**Fluke 5450A Resistance Calibrator:** This is a resistance standard with a range of 1 Ohm to 100 Megohms.

**HP 3325B Function Generator:** This instrument is an AC signal source for calibration of phase meters, electronic filters, low frequency attenuators, etc. It can provide output voltages of sine, triangle, square and ramp waveforms with modulation and range sweeping of desired frequencies.

**Fluke 6061A RF Signal Generator:** Similar to the above, this instrument provides a sine wave output up to 1.05 GHz with the option of FM or AM modulation. It is often used to verify the bandwidth capabilities in high frequency oscilloscopes.

**HP 6060A DC Electronic Load:** This is the main standard for calibration of power supplies. It provides three modes of operation/testing: constant voltage to 60 VDC, constant current to 60 Amps DC, resistive loads to 1000 ohms with input-short or input-open conditions.

**HP 5334B Counter:** This instrument is used to verify the frequency accuracy of signal outputs from UUTs such as test oscillators, signal and function generators, and other instruments which require accurate frequency for verification/alignment.

**Argo AS210 Frequency Standard System:** This standard is used to verify the input and time base accuracy of frequency counters.

**Tektronix CG5011 Scope Calibrator:** This instrument is used to verify oscilloscopes for measurement of signal amplitude and frequency, rise time, etc.

**Tektronix SC504 Oscilloscope:** This instrument is used to align UUTs and verify signal outputs.

**Ectron 1120 Thermocouple Simulator/Calibrator:** This instrument is used to calibrate temperature indicating devices such as thermocouple indicators and digital thermometers. It can also be used as a low-level DC voltage standard.

**HP 8903E Distortion Analyzer:** This instrument is used to measure output signal distortion of a UUT. It can also be used in the dB mode to calibrate a low-frequency attenuator.

**Eaton 1011A AC Ratio Standard:** This standard is primarily used in the calibration of small-signal amplifiers and conditioners.

With exception of the AC Ratio Standard and oscilloscope, all standards are IEEE-488 buss controllable.

FICS is also equipped with custom-designed hardware which is used in calibration of Neff Amplifiers and Edwards Signal Conditioners. The mobile system contains a rack that accommodates the Neff Model 122 family of wide band, differential DC amplifiers. These instrumentation amplifiers are widely used in research and test throughout LaRC. In 1985, Wyle designed and developed amplifier and signal conditioner test beds for use in the laboratory. The designs were adopted for use in FICS. The test beds are automated and controlled via IEEE-488 by the personal computer. A bank of Phillips 21/23 modular switching units are an integral part of the amplifier test bed. The modular switching units direct input signals to the amplifiers during the calibration process. The same bank of Phillips modular switching units are used to control calibration signals to the Edwards Signal Conditioners.

## **5.0**

### **FICS SOFTWARE**

#### **5.1     General Description**

Two major factors were considered in selecting software for FICS. The software had to enable the system operator to easily and quickly generate calibration procedures which are clear and readily executable. Also, the software had to be compatible with existing calibration standards and other system hardware. Among commercially available software packages, MET/CAL most comprehensively satisfied the above requirements.

FICS uses MET/CAL for data acquisition, calibration control and documentation. MET/CAL supports many core standards in FICS with built-in driver routines. C-based programs have been developed and used for calibration of specialized instruments with unusual interface or protocol requirements. With MET/CAL, the technician can generate and document calibration procedures without extensive training. These menu-driven procedures can instruct an inexperienced operator in the performance of step-by-step calibrations. Many existing instrument-control routines are directly compatible with FICS hardware. Fluke has a library of MET/CAL-structured calibration procedures that can be readily accessed for future requirements.

Calibration programs are routinely written to provide the operator with instructions for interconnecting equipment. After the UUT is connected to the system, the program directly controls the standards and UUT during the calibration process with little or no operator involvement. If the UUT is out-of-tolerance and can be adjusted via software, MET/CAL can provide correction of the UUT. If the UUT doesn't have an IEEE-488 interface, programs can be written to direct an operator through the proper procedure for a manual calibration, reducing the possibility of technician error. Within each procedure, the programmer can specify various parameters of a given calibration to guide the operator and produce the desired tests.

MET/CAL provides documentation for traceability to national standards, stores calibration procedures and records, tests for uncertainty ratios and adequacy of standards, alerts the operator of out-of-tolerance conditions, and generates calibration reports. Salient features of MET/CAL are summarized in Attachment B.

## 5.2 Detailed Description of a MET/CAL Calibration Procedure

MET/CAL was used to generate the calibration procedure shown in Attachment A. This procedure guides the calibration technician through the verification of a Beckman Model 300 Digital Multimeter.

The first line of the procedure is "INSTRUMENT". The information entered into this field by the technician becomes the procedure's file name for MET/CAL processing of this particular instrument. As such, no two procedures can share an identical name.

"DATE" is automatically furnished by the system's clock and date function. The "DATE" is revised every time the program is compiled.

"REVISION" is a MET/CAL option which permits the programmer to record the revision number for every program. After a program has been used to calibrate instruments, it should be saved and filed by name and revision prior to any modification. The procedure's name and revision number is recorded on the report of every instrument that is calibrated with FICS.

"ADJUSTMENT THRESHOLD" is the threshold of the UUT's out-of-tolerance condition which will trigger a requirement for adjustment. The adjustment threshold can be set by the programmer. Since this sample procedure does not provide for operator adjustment, adjustment threshold is not a factor.

"NUMBER OF TESTS; LINES" are automatically furnished by MET/CAL when the procedure is compiled.

"CONFIGURATION" is a list of instruments required to execute the program and is automatically furnished by MET/CAL when the procedure is compiled.

"STEP" is the test number and line number within the test. For example, 1.004 is test 1, line 4. The test number is advanced each time the procedure calls for a test evaluation. MET/CAL assigns the step numbers when the procedure is compiled. Multiple lines can have the same step number and are executed by the program at the same time.

"FSC" is Function Select Code. These commands are supported by MET/CAL, and are used to display information, set program execution parameters, math functions, designate memory location and/or content, address the IEEE interface, etc. In the sample procedure, ASK-/ + sets the execution parameters for the program. "+" turns a parameter on and "-" turns it off. For example, 1.002 ASK+ K sets the program to ask the operator for keyboard input of the UUT's indication at each test.

The "IEEE" FSC will directly access standards for which a Fluke-generated FSC program is unavailable or incomplete. Line 21.004 of Attachment A is an example. The FSC for the 5450A Resistance Calibrator does not automatically set up "2 Wire Comp" in the 5450A when a two wire connection is specified. The set up is accomplished by directly accessing the 5450A through the "IEEE" FSC and providing the appropriate command.

"RANGE" is the range setting of the instrument under test. This information is used by MET/CAL in the generation of data reports and equipment-connection messages during program execution.

"NOMINAL" is the operator-specified, nominal value of stimulus to be applied to the UUT.

"TOLERANCE" specifies the UUT's permissible tolerance. MET/CAL will accept the following tolerance formats: percent of nominal value, percent of range, absolute units, and parts per million. Refer to line 1.007 of the sample procedure. The range of the UUT is to be set at 200 mV. The 5700A is asked to provide 190mV DC as nominal. The tolerance of the test is +/- 0.5% (of nominal), +/-0.1 Unit (100uV - in this case, one count of the meter's display).

"MOD1, MOD2, 3, 4" designate various qualifiers to certain FSCs. MOD1 is used primarily to indicate frequency of AC volts. MET/CAL knows that AC volts are required through the 400H (400 Hz) designation under MOD1.

"CON" is used to designate the configuration of equipment connections; 2W(ire), 4W(ire), etc.

When the program is compiled, MET/CAL computes and indicates the Test Tolerance, System Tolerance, and TUR (Test Uncertainty Ratio) for each test evaluation. The system will flash a warning to the programmer should a test not meet specified TUR (in this case, 4 to 1). A summary of TUR evaluation appears at the end of the program. If the system cannot directly compute a TUR, it will inform the programmer to manually compute and record the TUR.

MET/CAL is user friendly and very comprehensive. This software permits an individual without an extensive computer background to develop and execute an automated calibration procedure. It establishes standardization in equipment testing and an excellent audit trail for calibration traceability. Although the calibration/verification technique is dictated by the programmer, MET/CAL significantly reduces the number of operator judgement calls. In short, MET/CAL reduces the potential for error, increases productivity, and consistently produces quality calibrations.

## 6.0 BENEFITS OF MOBILE CALIBRATION SYSTEMS

Prior to implementation of FELICS and FICS, an instrument user at LaRC could have general purpose test equipment calibrated only by sending it to the laboratory. This process typically involves routing the equipment and service request through the on site Instrument Control Unit (ICU) to Wyle. At the ICU, a work order for instrument service is generated and processed. After receipt at Wyle, the instruments are distributed to the calibration laboratory, and are scheduled for service in accordance with assigned priority. After the calibration is completed, the instrument is returned to the user through the ICU. Routinely, this entire process takes 10-12 days and involves considerable handling of the equipment by other than trained technicians.

On the other hand, having a mobile calibration system located in the user's facility significantly improves timeliness of calibration service and eliminates the cost of additional handling of the equipment. The total process for the on-site calibration of an instrument is routinely completed within hours, a significant reduction in downtime

of the research equipment. The mobile calibration service includes generation of all instrument-service requests and other requisite documentation, reducing the user's paperwork burden. The technician may assist the user with removal and reinstallation of calibrated equipment in the user's research system, and can offer consultation on proper use and operation of the user's instrumentation. Minimal handling of the instrument by other than a trained instrument technician reduces the potential of damage. If a problem arises during calibration, the user is immediately informed of the situation. Prior to taking additional action, the technician communicates all repair requirements and special operations to the user and the Wyle supervisor for approval.

## 7.0

### FUTURE EXPECTATIONS

The mobile calibration systems (FICS and FELICS) have been successfully implemented and widely accepted at LaRC. Users have recognized the benefits, and have made a number of suggestions to expand and enhance the systems. In the immediate future, FELICS will be upgraded. The Fluke 7411 controller will be replaced with an Industrial 486 personal computer and MET/CAL software, and an HP 3458A DMM will be installed.

LaRC and Wyle are examining the possibility of expanding the mobile systems' capability to service a larger selection of signal conditioners/amplifiers. This enhancement will require additional custom-developed hardware.

VXI buss-controlled instrumentation are gaining popularity in the research community. FICS and FELICS may be expanded to incorporate special hardware for calibration of test equipment with VXI interfaces.

Many equipment users have requested limited on-site calibration of thermal and pressure measurement instrumentation. Hart Scientific, Inc. manufactures a portable, thermal calibration furnace which generates temperatures from 200-1100°C with a stability of 0.75°C. A furnace of this type can provide FICS and FELICS with the capability to calibrate several types of thermocouples and thermal sensors. Many quartz-sensor, pressure indicators are now available for use as transfer standards in field calibrations.

In order to maximize the mobile stations' availability, LaRC is looking to reduce the downtime required for calibration of on board standards. The Fluke 5700A Calibrator, a key standard in the mobile calibration system and an extremely accurate instrument, is normally returned to Wyle's laboratory for a very lengthy calibration with primary standards. Datron has recently introduced a self-contained, programmable transfer standard which is capable of rapid, fully-automated calibrations of high performance multifunction calibrators such as the Fluke 5700A. Consideration is being given to the purchase of standards which can improve turnaround on certification of FICS and FELICS equipment.



## **8.0. CONCLUSION**

**FICS and FELICS are accurate and adaptable calibration stations. These mobile systems provide LaRC with the low cost and high efficiency of on site calibration service. These benefits consistently result in a high level of equipment-user satisfaction.**

# ATTACHMENT A

AL CART: FICS 615-20

MET/CAL Procedure

```
=====
INSTRUMENT:      BECKMAN 300 DMM
DATE:            18-Feb-93
AUTHOR:          C.BROWN
REVISION:        1.0
ADJUSTMENT THRESHOLD: 100%
NUMBER OF TESTS: 37
NUMBER OF LINES: 130
CONFIGURATION:   Fluke 5700A
CONFIGURATION:   Fluke 5725A
CONFIGURATION:   Fluke 5450A
=====
```

STEP	FSC	RANGE	NOMINAL	TOLERANCE	MOD1	MOD2	3	4	CON
1.001	ASK-			P		F			W
1.002	ASK+		K						
1.003	HEAD		INITIAL SET-UP						
1.004	DISP		Verify Battery and replace as necessary						
1.004	DISP								
1.004	DISP		Verify fuse and replace as necesesary						
1.005	HEAD		(DC Volts)						
1.006	DISP								
1.006	DISP		Connect: 5700 HI to UUT V-[234]						
1.006	DISP								
1.006	DISP		Connect: 5700 LO to UUT COM						
1.007	5700	200	190mV	0.5% 0.1U					2W
#!			Test Tol 0.00105, Sys Tol 2.51e-006, TUR 418.327 (>= 4.00).						
2.001	5700	2	1.9V	0.5% 0.001U					2'
#!			Test Tol 0.0105, Sys Tol 1.64e-005, TUR 640.244 (>= 4.00).						
3.001	5700	20	19V	0.5% 0.01U					2W
#!			Test Tol 0.105, Sys Tol 0.00016, TUR 656.250 (>= 4.00).						
4.001	5700	200	190V	0.5% 0.1U					2W
#!			Test Tol 1.05, Sys Tol 0.00181, TUR 580.110 (>= 4.00).						
5.001	5700	1500	1000V	0.5% 1U					2W
#!			Test Tol 6, Sys Tol 0.0116, TUR 517.241 (>= 4.00).						
6.001	HEAD		(AC Volts @ 400Hz , 3KHz , 10KHz)						
6.002	DISP		Make sure 5700 has settled ("u" OFF)						
6.002	DISP		before entering UUT reading						
6.003	5700	200	190mV	1.5% 0.4U	400H				2W
#!			Test Tol 0.00325, Sys Tol 3.09e-005, TUR 105.178 (>= 4.00).						
7.001	5700	200	190mV	2.0% 0.5U	3kH				2W
#!			Test Tol 0.0043, Sys Tol 3.09e-005, TUR 139.159 (>= 4.00).						
8.001	5700	200	190mV	3.0% 0.9U	10kH				2W
#!			Test Tol 0.0066, Sys Tol 3.09e-005, TUR 213.592 (>= 4.00).						
9.001	5700	2	1.9V	1.5% 0.004U	400H				2W
#!			Test Tol 0.0325, Sys Tol 0.0001685, TUR 192.878 (>= 4.00).						
10.001	5700	2	1.9V	2.0% 0.005U	3kH				2W
#!			Test Tol 0.043, Sys Tol 0.0001685, TUR 255.193 (>= 4.00).						
11.001	5700	2	1.9V	3.0% 0.009U	10kH				2W
#!			Test Tol 0.066, Sys Tol 0.0001685, TUR 391.691 (>= 4.00).						
12.001	5700	20	19V	1.5% 0.03U	400H				2W
#!			Test Tol 0.315, Sys Tol 0.001685, TUR 186.944 (>= 4.00).						
13.001	5700	20	19V	2.0% 0.05U	3kH				2''
#!			Test Tol 0.43, Sys Tol 0.001685, TUR 255.193 (>= 4.00).						
14.001	5700	20	19V	3.0% 0.09U	10kH				2W
#!			Test Tol 0.66, Sys Tol 0.001685, TUR 391.691 (>= 4.00).						
15.001	5700	200	190V	1.5% 0.3U	400H				2W
#!			Test Tol 3.15, Sys Tol 0.0181, TUR 174.033 (>= 4.00).						

Continued...

16.001	5700	200	190V	2.0% 0.5U	3kH		2W
			Test Tol	4.3, Sys Tol 0.0181, TUR 237.569 (>= 4.00).			
17.001	5700	200	190V	3.0% 0.9U	10kH		2W
#!			Test Tol	6.6, Sys Tol 0.0181, TUR 364.641 (>= 4.00).			
18.001	5700	1000	1000V	1.5% 3U	400H		2W
#!			Test Tol	18, Sys Tol 0.094, TUR 191.489 (>= 4.00).			
19.001	5700	1000	1000V	2.0% 5U	3kH	B1	2W
#!			Test Tol	25, Sys Tol 0.171, TUR 146.199 (>= 4.00).			
20.001	5700	1000	1000V	3.0% 9U	10kH	B1	2W
#!			Test Tol	39, Sys Tol 0.171, TUR 228.070 (>= 4.00).			
21.001	5700		*			S	
21.002	HEAD		{Ohms}				
21.003	ASK+						W
21.004	IEEE		[@5450] 2 WIRE COMP ON				
21.005	5450	200	190Z	0.75% 0.1U			2W
#!			Test Tol	1.525, Sys Tol 0.014945, TUR 102.041 (>= 4.00).			
22.001	IEEE		[@5450] 2 WIRE COMP ON				
22.002	5450	2	1.9kZ	0.75% 0.001U			2W
#!			Test Tol	15.25, Sys Tol 0.0597, TUR 255.444 (>= 4.00).			
23.001	IEEE		[@5450] 2 WIRE COMP ON				
23.002	5450	20	19kZ	0.75% 0.01U			2W
#!			Test Tol	152.5, Sys Tol 0.3625, TUR 420.690 (>= 4.00).			
24.001	IEEE		[@5450] 2 WIRE COMP ON				
24.002	5450	200	190kZ	0.75% 0.1U			2W
#!			Test Tol	1525, Sys Tol 3.565, TUR 427.770 (>= 4.00).			
25.001	IEEE		[@5450] 2 WIRE COMP ON				
25.002	5450	2	1.9MZ	0.75% 0.001U			2W
			Test Tol	15250, Sys Tol 36.1, TUR 422.438 (>= 4.00).			
26.001	IEEE		[@5450] 2 WIRE COMP ON				
26.002	5450	20	19MZ	1.5% 0.01U			2W
#!			Test Tol	2.95e+005, Sys Tol 1064, TUR 277.256 (>= 4.00).			
27.001	5450		*			S	
27.002	HEAD		{DC Current}				
27.003	ASK-						W
27.004	DISP						
27.004	DISP		Connect: 5700 HI to UUT A				
27.004	DISP						
27.004	DISP		Connect: 5700 LO to UUT COM				
27.005	5700	200	190uA	1.00% 0.1U			2W
#!			Test Tol	2e-006, Sys Tol 2.14e-008, TUR 93.458 (>= 4.00).			
28.001	5700	2	1.9mA	1.00% 0.001U			2W
#!			Test Tol	2e-005, Sys Tol 1.24e-007, TUR 161.290 (>= 4.00).			
29.001	5700	20	19mA	1.00% 0.01U			2W
#!			Test Tol	0.0002, Sys Tol 1.24e-006, TUR 161.290 (>= 4.00).			
30.001	5700	200	190mA	1.00% 0.1U			2W
#!			Test Tol	0.002, Sys Tol 1.43e-005, TUR 139.860 (>= 4.00).			
31.001	5700	2	1.9A	1.00% 0.001U			2W
#!			Test Tol	0.02, Sys Tol 0.0002105, TUR 95.012 (>= 4.00).			
32.001	HEAD		{AC Current @ 400Hz}				
32.002	DISP		Make sure 5700 has settled before entering				
32.002	DISP		UUT readings.				
32.003	DISP		Connect: 5700 HI to UUT A				
32.003	DISP						
32.003	DISP		Connect: 5700 LO to UUT COM				
32.004	5700	200	190uA	2.0% 0.4U	400H		2W
#!			Test Tol	4.2e-006, Sys Tol 5.04e-008, TUR 83.333 (>= 4.00).			
33.001	5700	2	1.9mA	2.0% 0.004U	400H		2W
#!			Test Tol	4.2e-005, Sys Tol 3.44e-007, TUR 122.093 (>= 4.00).			

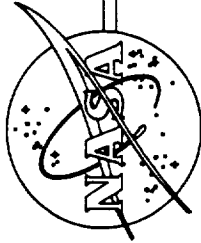
34.001	5700	20	19mA	2.0% 0.04U	400H	2W
#!	Test Tol 0.00042, Sys Tol 3.44e-006, TUR 122.093 ( $\geq 4.00$ ).					
35.001	5700	200	190mA	2.0% 0.4U	400H	2W
#!	Test Tol 0.0042, Sys Tol 3.44e-005, TUR 122.093 ( $\geq 4.00$ ).					
36.001	5700	2	1.9A	2.0% 0.004U	400H	2W
#!	Test Tol 0.042, Sys Tol 0.001465, TUR 28.669 ( $\geq 4.00$ ).					
37.001	5700	*				S
37.002	HEAD					
37.003	DISP This concludes the verification !!!					
#!	T.U.R.s less than 4.00:					0
#!	T.U.R.s estimated using RANGE value:					0
#!	T.U.R.s not calculated (ASK- U):					0
#!	T.U.R.s not computable at compile time:					0
#! FOR JUSTIFICATION REFER TO COMMENTS FOLLOWING EACH TEST IN THIS LISTING.						

# ATTACHMENT B

## WHY MET/CAL ?

<i>MET/CAL Feature</i>	<i>Value to Customer</i>
<i>Upward Traceability</i>	<i>Complies with ISO 9001, 4.11b or MIL-STD-45662A, 5.2; traceability to national standards</i>
<i>Calibration Records</i>	<i>Complies with ISO 9001, 4.11f or MIL-STD-45662A, 5.9; calibration records</i>
<i>Calibration Procedures</i>	<i>Complies with ISO 9001, 4.11c or MIL-STD-45662A, 5.5; documented cal procedures</i>
<i>Out of tolerance reporting</i>	<i>Complies with ISO 9001, 4.11g or MIL-STD-45662A, 5.6; out-of-tolerance conditions</i>
<i>Test Uncertainty Ratio (TUR) calculation</i>	<i>Complies with ISO 9001, 4.11d or MIL-STD-45662A, 5.2; adequacy of standards</i>
<i>Environmental conditions logged</i>	<i>Complies with ISO 9001, 4.11h or MIL-STD-45662A, 5.3; environmental conditions</i>
<i>Drives a wide range of popular calibration instruments. With enhanced IEEE FSC, controls virtually any IEEE instrument</i>	<i>Provides coverage of the desired workload</i>
<i>Consistent, repeatable calibration results</i>	<i>Provides reliable data base for continuous quality improvement</i>
<i>Fast procedure execution and immediate documentation cut individual cal times</i>	<i>Increases throughput while controlling cal costs, which increases cal productivity</i>
<i>Closed-loop, closed-case cal delivers hands-off calibrations</i>	
<i>Computer-aided cal permits reliable execution of procedures by low skilled technicians</i>	<i>Conserves scarce technician time for more challenging tasks</i>
<i>Fast procedure execution delivers short turnaround, minimizing customer's downtime</i>	<i>Satisfies the calibration customer</i>
<i>Large installed base</i>	<i>Promotes sharing of experience across user community</i>
<i>Instantly disconnects all stimulus instruments upon system interrupt</i>	<i>Insures operator safety</i>
<i>Adapts previous MET/CAL and 7411 procedures</i>	<i>Protects investment in procedures</i>
<i>Four security levels</i>	<i>Safeguards your calibration data</i>
<i>Powerful procedure editing, flexible output formatting</i>	<i>Allows calibration procedures and documents to match your company's practices</i>
<i>Tutorial (Sample Version), context sensitive help, documentation, phone/fax/bulletin board support, training (optional)</i>	<i>Promotes quick startup, early productivity</i>





## WHITE SANDS TEST FACILITY

### CENTER LINE ADJUSTMENT UPDATE

KEN SCHAAF

1993 ANNUAL NASA METROLOGY

AND

CALIBRATION WORKSHOP

APRIL 20, 21, & 23, 1993



## **CENTER LINE ADJUSTMENT UPDATE**

### **○ REVIEW**

**● ISSUES**

**● SURVEY**

**● PROCEDURES**

**WRITTEN**

**NONE**

**● NAVY TEST**



# **CENTER LINE ADJUSTMENT UPDATE**

## **○ NAVY TEST UPDATE**

### **● TEST OBJECTIVES**

**IDENTIFY TEST EQUIPMENT**

**DEVELOP EXPERIMENT MANUAL**

**PERFORM EXPERIMENT**

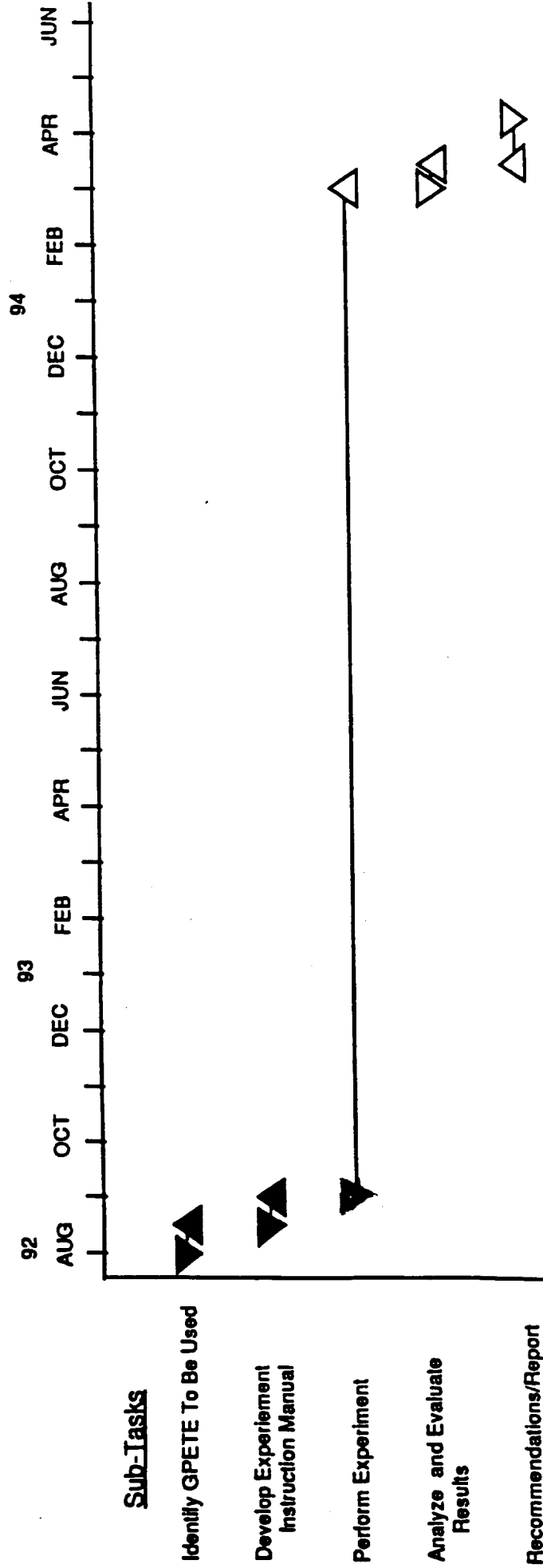
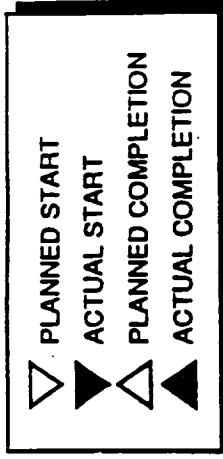
**ANALYZE RESULTS**

**DEVELOP REPORT AND RECOMMENDATIONS**

# TASK: CALIBRATION ADJUSTMENT EXPERIMENT

NWSC Project Coordinator: J. WITHEM

DATE: 24 AUGUST 1992



# COMMITTEE REPORTS





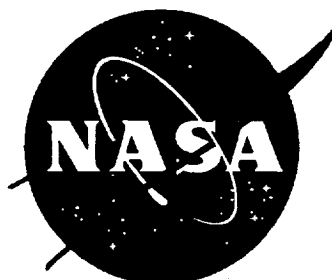
# **Space Station *Freedom* Metrology**

## **The WP-01 Approach**

**Presented to the NASA Metrology  
Working Group 16th Annual Workshop  
April 21, 1993**

**By  
Randy Humphries Jr.**

**NASA Marshall Space Flight Center  
Huntsville, Alabama**



## **I. INTRODUCTION**

The word metrology refers to a wide variety of aspects of the measurement process. The following definition is offered to assist in understanding what metrology means to the Space Station Freedom and therefore what this paper addresses.

### *Space Station Freedom Metrology:*

It is "The ability of the flight systems and associated instrumentation to maintain the required accuracy over the specified period of operation. " For the Space Station that means a 30 year life.

## **II. SPACE STATION FREEDOM OVERVIEW**

With that in mind an overview of the Space Station Freedom is in order. Figure 1. shows the Space Station as it exist today along with who is responsible for design and construction of each element. NASA has international agreements with 1) The European Space Agency (ESA), 2) Japan and 3) Canada. ESA is working on a Pressurized Laboratory Module, a Polar Platform and the Man Tended Free Flyer. The Japanese are undertaking a Pressurized Laboratory module that has an exposed facility and an experiment Logistics Module. Canada will be constructing the Mobile servicing center.

NASA has three centers responsible for different portions of the Space Station: Lewis Research Center (WP-04) has the Photovoltaic power modules and the Electrical Power System (EPS); Johnson Space Center (WP-02) is in charge of the Truss, Mobile transporter, nodes and airlocks as well as systems including the External Thermal Control, External Vehicular Activity (EVA), Data Management System (DMS), Communications and Tracking, Guidance Navigation & Control (GN&C), propulsion and the National Space Transportation Systems (NSTS) attachment systems. Marshall Space Flight Center (WP-01) is responsible for the pressurized shells for the nodes, the Habitation, Laboratory and Logistics modules, and the Internal Thermal Control System (ITCS), Internal Audio/Video (IA/V) and Environmental Control and Life Support Systems (ECLSS).

# Space Station Freedom

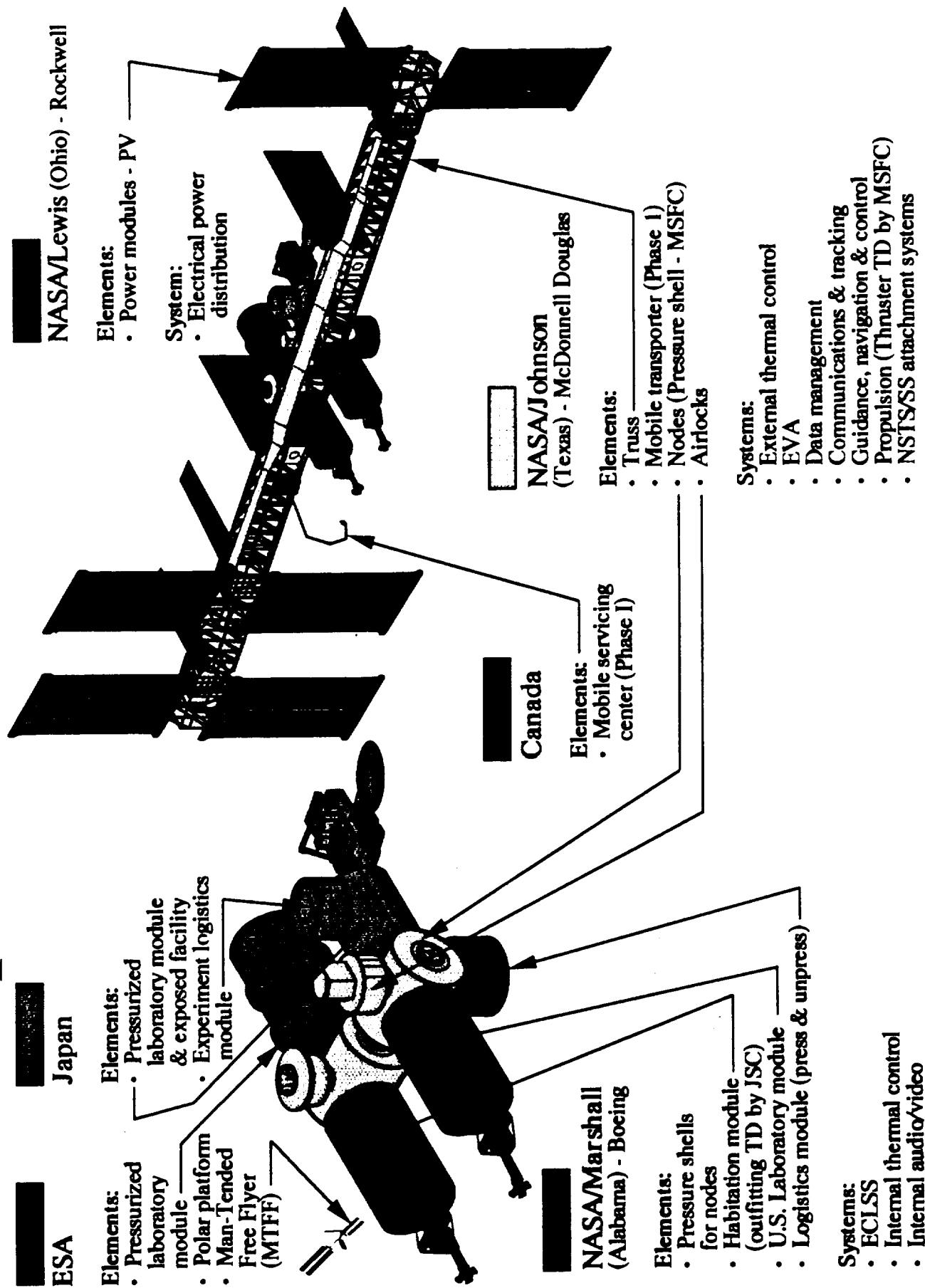


FIGURE 1

The ECLSS systems include a] Air Revitalization, b] Fire Detection and Suppression, c] Atmosphere Control and Supply, d] Temperature and Humidity Control, e] Water Recovery and Management and f] Waste Management System.

Construction of the Space Station will be accomplished in three major phases:

- 1) Man Tended Configuration or MTC, where the shuttle will dock with the Station and remain attached while the experiments are performed. MTC is scheduled for 1997.
- 2) Permanently Manned Configuration or PMC when we will establish our presents in space without the requirement for the shuttle. PMC is projected to be in 1999.

and

- 3) Eight Man Crew Capability (EMCC) will occur some time after the year 2000 when the the full Space Station freedom is scheduled to be in orbit as seen in figure 1.

### **III. SPACE STATION *FREEDOM* WP-01 METROLOGY HISTORY**

When asked to suggest coverage topics for this report, Mr. Robert Burdine<sup>4</sup> thought three specific areas important to address.

- 1) WHAT HAS BEEN DONE IN THE AREA OF SSF METROLOGY?
- 2) WHAT IS THE CURRENT STATUS?
- 3) WHAT MIGHT THE WORKING GROUP DO TO ASSIST SSF?

#### **1) WHAT HAS BEEN DONE?**

##### **A) SSF METROLOGY BACKGROUND**

In 1989 Martin Marietta<sup>1</sup> and Vitro Corporation<sup>2</sup> performed studies of On-Orbit Metrology and Calibration Requirements for Space Station Freedom. Their findings concluded the unique challenge of ensuring long term performance in a system that was not readily accessible to engineers and technicians. The studies cited candidates for on-orbit calibration and provided recommendations of on-orbit calibration requirements, and the need for further



development of measurement/calibration equipment and techniques to meet space-based metrology concerns.

Most recently the NASA Metrology Working Group, formed the Spaced based Metrology Committee to begin addressing needs for long duration missions. As a result, significant work has been performed toward the development of a NASA Metrology, Calibration & Measurement Processes Guidelines Handbook<sup>3</sup> with specific orientation toward long-term space operation.

Although the studies and initiatives verified the need for serious consideration of SSF metrology, they followed requirements development and were never incorporated into the design requirements. Technical interchange meetings and impromptu discussions addressed the issue at various stages, but without the teeth of a requirement, little if any design changes resulted.

#### B) WP-01 METROLOGY

A group of Marshall Space Flight Center engineers had also been trying to get attention focused on metrology. In 1991, at the WP-01 Preliminary Design Review (PDR) a Review Item Discrepancy or RID was written against all WP-01 development plans. The RID addressed the lack of consideration of the long term integrity of the measurements. The resulting action was two-fold. First, the formation of a metrology committee consisting of Marshall and Boeing engineers; and second the development of a Metrology Plan. The WP-01 metrology committee took on the task of directing the development of the plan while simultaneously implementing a test case.

The basic metrology plan was developed over a period of 9 months and included input from the previously cited studies, Marshall and Boeing personnel and the NASA Space Based Metrology subcommittee. The impetus behind the plan is the direction of WP-01 flight metrology activities. It provides the metrology approach, philosophies, criteria and processes with the purpose of assuring the long term integrity of operations and performance for the on-orbit systems. The plan is written as volume II of the System Engineering and Integration Plan (D683-10084-3).

**C) METROLOGY TEST CASE**

The Internal Thermal control System (ITCS) was chosen as the test case to study the feasibility and application of the design-based metrology philosophy. Primary concerns in performing the study included:

- The design existed at a reasonably mature stage and therefore time constraints predicated the need to focus on only the most serious design concerns.
- The overriding Space Station maintenance philosophy was removal and replacement of failed equipment.
- No previous on-orbit calibration experience existed.

The Boeing ITCS personnel were furnished with the Martin Marietta and Vitro studies as well as the draft copy of the NASA Metrology Handbook. They were also given some basic instructions to:

- Assess the functional accuracy
- Investigate the measurement difficulty
- Define their need for verification or calibration
- Develop a plan to control ITCS measurement uncertainties
- and finally, Flow appropriate changes into documentation

Their findings were as follows:

- The Failure Modes and Effects Analyses did not contain Out-Of-Tolerance as a plausible failure mechanism and would have to be updated..
- Verification for the ITCS could be accomplished on the ground utilizing telemetered data.
- They would write closed loop equations using causal relations to compare sensors.
- A flowmeter needed to be added to allow the ground verification to be accomplished.

and most importantly, the test case

- Verified the need to include other functional organizations in the metrology study.

#### D) COMMITTEE ACTIVITIES

In addition to the development of the plan, following the successful test case, two major reviews were held. The first review of all WP-01 systems was covered on August 11th and 12th of 1992. The presentations focused on the sensors, their accuracy and methods to be used to verify.

The results produced a need to:

- Examine sensor historical data
- Define process to calculate Mean Time Between Out Of Tolerance (MTBOOT), and confirmed an earlier suspicion that the
- Multiplexer DeMultiplexer (MDM) tolerance was driving sensor accuracy in some cases. The MDM is the signal conditioning and A/D conversion portion of the Data Management System (DMS).

As a result of this third finding, and the fact that WP-01 is not charged with MDM design responsibility, additional analysis was performed and the issue of MDM accuracy was taken to an inter-center Engineering Design Council (EDC) for deliberation and decision making.

The second review took place in December of 1992. During a two day period the WP-01 subsystems presented fault detection methods for drift/Out-Of-Tolerance detection.

Each subsystem designer was given the Sensor Tolerance Maintenance Decision Matrix (figure 2) to be used for assessment of sensor out-of-tolerance detection. The matrix was designed by Mr. Bill Hyman<sup>5</sup> of Boeing-Huntsville as a tool or guide for the system designers. Followed properly, and using viable fault detection rationale, the matrix identifies the level the detection takes place, and/or mandates a design change.

The designers listed all sensors as to whether they were discrete or analog measurements, and if they had imbedded processors. The list of sensors showed the criticality category and the design condition as determined from the matrix. Also the rationale for how OOT was detected was explained. The decision matrix was

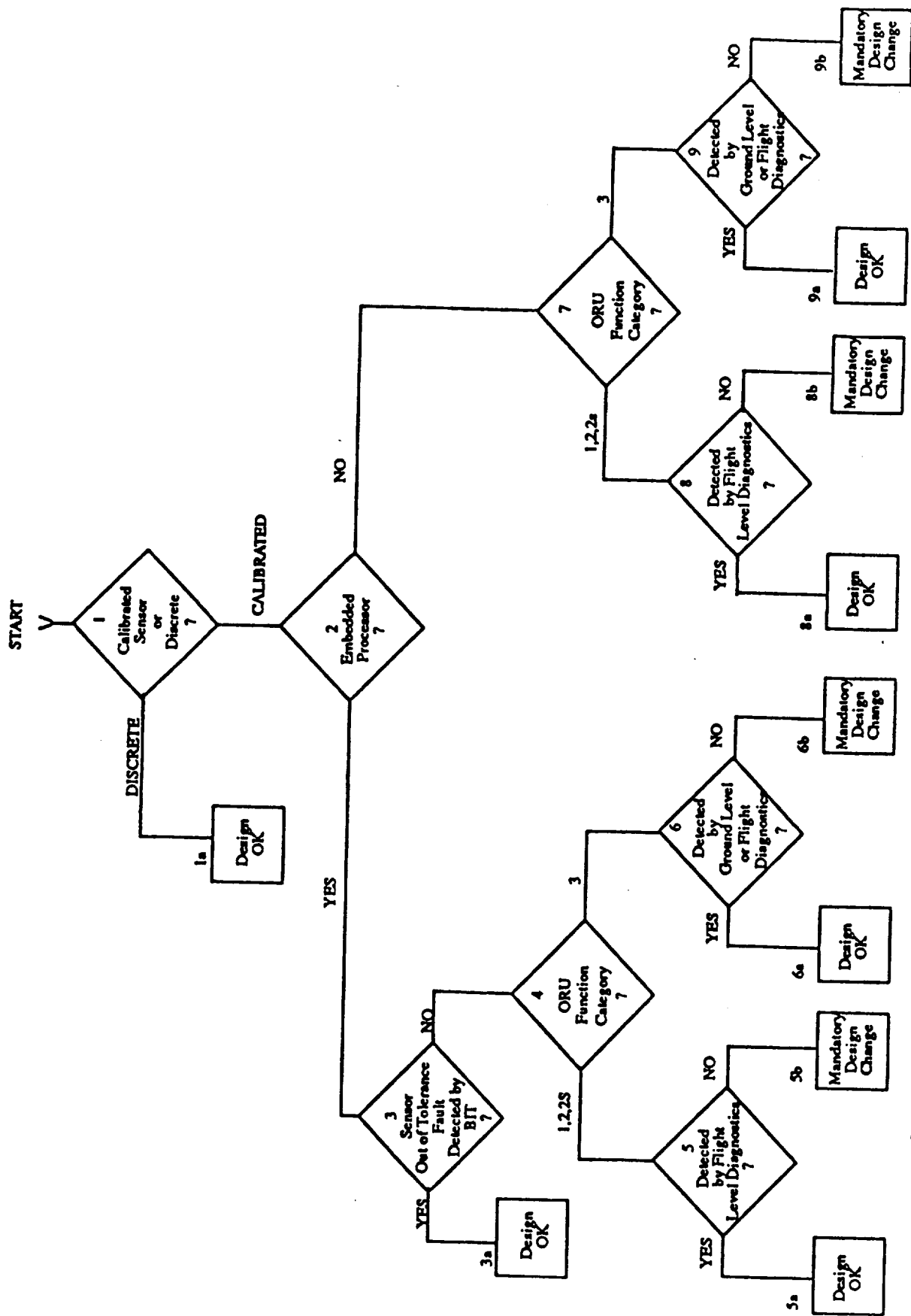


FIGURE 2 SENSOR TOLERANCE MAINTENANCE DECISION MATRIX

simple, yet effective. The designers now had a clearer understanding of the issues.

Still, some evolution of change issues existed. In specific the process of using two co-located identical sensors checked against each other to determine OOT was a common practice, and sensor accuracy requirements were still not derived from subsystem functional requirements.

## 2) WHAT IS THE CURRENT STATUS?

The WP-01 Man Tended Configuration Critical Design Review (MTC CDR) will be complete at the end of April. Review Item Discrepancies (RID's) have been written against the fault detection methods, the sensor specifications and probably most importantly against the Analyses and Analytical Models.

The RID shown in figure 3 was written against all WP-01 systems and will, along with individual instrumentation RID's, be used to assure closure of metrology issues.

In general the WP-01 MTC CDR documentation reflect a willingness to address system metrology. The detailed analyses and supporting information continue to be developed. Lack of comprehensive CDR metrology data is mainly due to a knowledge void as well as time constraints. Remember, most of the designers received emphasis area action items only after the test case was completed in May of 1992.

Significant advances made to date include:

- Reliability and Maintainability documentation now reflect OOT as a plausible fault condition.
- Preliminary accuracy analyses have surfaced system instrumentation needs not known prior to this effort.
- The EDC action resulted in a trade study to evaluate the impact of MDM changes against either sensor enhancements or requirements relaxation.
- Fault detection analyses produced the need for additional sensors in one system and identified the existence of too many in another.

1. Phone: 544-3443 Initiator: Randy Humphries Jr. Organization No.: EB22	<b>REVIEW ITEM DISCREPANCY (RID)</b>	3. Review: _____ Track #: _____ End Item: _____ 4. RID #: _____
2. Team: <u>GENERAL</u>	6. Doc #: <u>SE 27</u> Page: _____ Name: <u>ANALYSES &amp; ANALYTICAL MODEL</u> Sec: _____ Para: _____ Ver: _____ Part: _____	
7. Discrepancy/Problem:  <p><b>TITLE: SENSOR/INSTRUMENTATION ACCURACY</b>          Each subsystem of a measurement system contributes errors which combine to produce a composite measuring system error. If instrumentation data is to be useful for implementing redline limits, condition checking and control windows, the inaccuracies introduced by the instrumentation system must be included. An investigation to determine errors associated with transducers, signal conditioners and telemetry links should be included. The analysis should include beginning and end-of-life accuracies.</p>		
8. Recommendation: Submit for review, instrumentation accuracy analysis to verify subsystem design criteria.		
9. Subcontractor's Comments:          <div style="display: flex; justify-content: space-between;"> <div>Signature: _____</div> <div>Impact (Y/N): _____</div> </div>		
10. Team Captains disposition: (check one block Only) <div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <input type="checkbox"/> Approved per Block 8  <input type="checkbox"/> Approved per Block 9  <input type="checkbox"/> Approved per Remarks  <input type="checkbox"/> Disapproved         </div> <div style="width: 45%;"> <input type="checkbox"/> Closed  <input type="checkbox"/> Subcontractor's Explanation Satisfactory  <input type="checkbox"/> Withdrawn  <input type="checkbox"/> Withdrawn with comments  <input type="checkbox"/> Combined with RID #: _____         </div> </div> <div style="margin-top: 10px;">         Actionee: _____          Due Date: _____          Remarks: _____       </div>		

FIGURE 3

- Removal and replacement intervals are being adjusted to meet realistic sensor OOT intervals.

The progress in these areas encourage the undertaking of the tasks ahead.

- OOT detection methods need reviewing for adequacy and should be supported by analyses. Some education of proper detection methods will probably be necessary.
- Instrumentation/sensor accuracy requirements need traceability to the system design requirements.
- An error budget/accuracy analysis needs to be included with all measurements particularly on criticality 1 systems. Inclusion of instrumentation drift predictions and/or test data is considered part of the process.
- A majority of the SSF WP-01 systems utilize evaluation of telemetered data to verify tolerance bands. A telemetry impact assessment should be performed to confirm this theory. Additionally, any tolerance limits/uncertainties associated with the telemetry link should be included in the measurement accuracy analyses.
- On-orbit and ground drift detection methods rely on software algorithms for automated processing of the data. Verification of the software should be integrated into a error simulation system.

### THE FUTURE

The WP-01 SSF metrology outlook involves following the metrology plan and schedule, and proper closure of CDR RID's. What is meant by the last statement is that, reply's to all RID's must be reviewed and accepted by the writer of the RID.

Space Station metrology is an iterative activity and as such welcomes suggestions to improving the process. As for future programs and vehicles the following suggestions are offered:

- Produce documentation to show the derivation of instrumentation requirements from the system requirements.
- Include accuracy analyses with tolerances on all measurements in the instrumentation stream.
- Assure the inclusion of Out-Of-Tolerance predictions in the Failure Mode and Effects Analysis (FMEA) and the method by which the condition will be detectable.
- Where necessary, perform analysis to verify detection methods.
- For long term space missions, conduct design trades to optimize designs i.e. the cost of maintenance and resupply logistics against design for calibration.

In short, instrumentation requirements and selection needs to incorporate design traceability. Selection of the sensors and careful control of the instrumentation design parameters should be an integral part of the design process.

Our future long duration manned space programs cannot preclude the possibility of on-orbit calibration. Calibration must be considered equal in the trades and analyses.

### 3) WHAT CAN THE WORKING GROUP DO?

The NASA Metrology and Calibration Working Group would seem to have a vested interest in space-based metrology. The technology advances that can come from the need to extend calibration periods and the knowledge of space exploration as it pertains to metrology can only serve to move the field of metrology forward and bring the design community closer. To that end the following general recommendations are offered:

- We must work on fostering relationships between the flight design community and metrology body. The service here will benefit both parties.
- A cooperative effort between the design and metrology public to complete the NASA handbook is a good starting point



towards accomplishing the above and will serve as a needed design tool for both organizations.

- Establishment of design standards that include design-based metrology. This means incorporation of requirements in all future documentation.
- Education of the design people about the science of measurement. It isn't that the design community doesn't want to incorporate metrology, it's that they don't fully understand the benefits it can bring to the designs. A collaborative effort of understanding the needs and accepting a team approach will again benefit both parties.

## **CONCLUSIONS**

The WP-01 program has acknowledged the challenges of metrology and is working forward in a team effort to identify all potential problems and to solve them to the benefit of long term system integrity while working under program constraints.

## REFERENCES:

1. ON-ORBIT METROLOGY AND CALIBRATION REQUIREMENTS FOR SPACE STATION ACTIVITY DEFINITION STUDY.  
Final Report, April 1989. G. M. Cotty, B. N. Ranganathan and A. L. Sorrell, Martin Marietta Manned Space Systems; New Orleans, LA. Prepared under contract NAS14-303 for NASA
2. DEFINITION/PLANNING ON-ORBIT METROLOGY and CALIBRATION REQUIREMENTS for the SPACE STATION "FREEDOM".  
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3. METROLOGY, CALIBRATION, & MEASUREMENT PROCESSES GUIDELINES (Working Copy). NHB 5330.9(1A)
4. Robert Burdine is the NASA code QR program manager for Metrology and Non-Destructive Evaluation. In 1991 Mr. Burdine served on the SSF WP-01 Metrology committee.
5. Bill Hyman is the Space Station *Freedom* WP-01 Flight Metrology Manager for The Boeing Company in Huntsville, Alabama.

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Randy Humphries Jr.

Instrumentation Branch (EB22)

Marshall Space Flight Center, Alabama 35812

(205)544-3443

## 1992 Space-Based Metrology Activities

- February - Tele-conference
  - Committee Objectives
  - Mission Statement
  - Operating Procedure
- March - Travel to Marshall, SSF WP01
  - Presented MCWG overview
  - Metrology Design Process
- May - Contact by Robert Rafner, Grumman QA, level II SSF
- June - JSC contacted by Man-System/SP on equipment requirements
- July - Reviewed MSFC SSF Metrology Plan
- August - JSC involved with On orbit Mass Experiment
- September - MFSC releases WP01 Metrology Plan
  - JSC - reviews Man Systems/SP44 on-orbit
- October - Travel to HQ presented White Paper



**JOHNSON SPACE CENTER  
MEASUREMENT STANDARDS AND CALIBRATION LABORATORY  
SPACE-BASED METROLOGY COMMITTEE STATUS REPORT**

**ON-ORBIT MEASUREMENT EQUIPMENT ACTIVITIES**

**PREPARED AND PRESENTED BY:  
RON D. SMITH  
SIMCO ELECTRONICS  
APRIL 20-22, 1993**

# **JOHNSON SPACE CENTER**

## **MEASUREMENT STANDARDS AND CALIBRATION LABORATORY ON-ORBIT MEASUREMENT EQUIPMENT ACTIVITIES**

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**JSC FLIGHT CREW SUPPORT DIVISION (FCSD) / SP 44**

- \* SPACE STATION MISSION BUILD 6 (MB-6); DECEMBER 1996**
- \*\* SUPPORT FCSD CALIBRATION OF SS ON-BOARD EQUIPMENT**
- \*\* A LOCKER SPACE OF 1.2 CUBIC FEET FOR CALIBRATION STANDARDS**

# **JOHNSON SPACE CENTER**

## **MEASUREMENT STANDARDS AND CALIBRATION LABORATORY ON-ORBIT MEASUREMENT EQUIPMENT ACTIVITIES**

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### **PRESENTATION SUPPORT ON CALIBRATION EQUIPMENT REQUIREMENTS FOR FCSD ON-BOARD DIAGNOSTIC EQUIPMENT AND TOOLS**

#### **FOLLOWING LIST OF EQUIPMENT WAS ANALYZED FOR CALIBRATION STANDARDS SUPPORT REQUIREMENTS:**

- \* LOGIC ANALYZER: TEKTRONIX 1230B**
- \* FUNCTION/SWEEP GENERATOR: HP 8116A**
- \* MULTIMETER: FLUKE 87**
- \* POWER SUPPLY: SORENSEN DC150-7**
- \* TORQUE WRENCHES: 30 - 200 INCH POUNDS (2)**
- \* MICROMETER: 0 - 1 INCH**
- \* BATTERY CHARGER**
- \* COMPUTER**

**STATUS REPORT: APRIL 20-22, 1993**

# **JOHNSON SPACE CENTER**

## **MEASUREMENT STANDARDS AND CALIBRATION LABORATORY ON-ORBIT MEASUREMENT EQUIPMENT ACTIVITIES**

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### **FCSD ON-BOARD EQUIPMENT USAGE**

**\* STS-57 SPACEHAB 1 MISSION (APRIL-MAY 1993)**

#### **\*\* CREW MAINTENANCE SCENARIOS**

- GROUND BASED SOLUTIONS UPLINKED TO ORBIT**
- CREW DIAGNOSIS, TEST, AND APPLICATION**



# **JOHNSON SPACE CENTER**

## **MEASUREMENT STANDARDS AND CALIBRATION LABORATORY ON-ORBIT MEASUREMENT EQUIPMENT ACTIVITIES**

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### **MAN-SYSTEMS WORKING GROUP**

- \* REVIEWED SPACE STATION DOCUMENT FOR METROLOGY REFERENCES.**

### **THE DOCUMENT REVIEWED WAS:**

**\*\* NASA-STD 3000, "SSF MAN-SYSTEMS INTEGRATION STANDARD,"  
SECTION 12.3.2, "TESTABILITY DESIGN REQUIREMENTS"**

### **THE TOPICS REVIEWED WERE:**

- OUT-OF-TOLERANCE**
- TEST EQUIPMENT VERIFICATION**
- TEST EQUIPMENT ACCURACY**
- ADJUSTMENT CONTROLS**
- CALIBRATION DAMAGE**
- SELF CHECKING**
- TESTING AND SERVICING**

**STATUS REPORT: APRIL 20-22, 1993**





# **A Systems Approach to Space-Based Metrology**

**16th ANNUAL NASA  
METROLOGY & CALIBRATION WORKSHOP  
Rockville, MD**

**21 April 1993**

**R.E. Martin**

**Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California, USA**



## **Contents**

- **Mission and operational requirements**
- **Measurement process quality considerations**
- **Measurement process design goals**
- **Reliability through redundancy**
- **Concept of “virtual” measurement**
- **Uncertainty control and audit by SMPC**
- **Self-test, self-calibrate sensors**
- **System development methodology**
- **System architecture**
- **Future metrology role**

## **Background**

- **Space missions involve complex instrumentation and science operations over long durations and real-time adaptation to complex and uncertain situations.**
- **Dual requirements of safety and economy dictate reduced direct human involvement and more autonomy in both the space and ground systems.**
- **Difficult requirements of long duration and high reliability are imposed on measurement and control processes.**

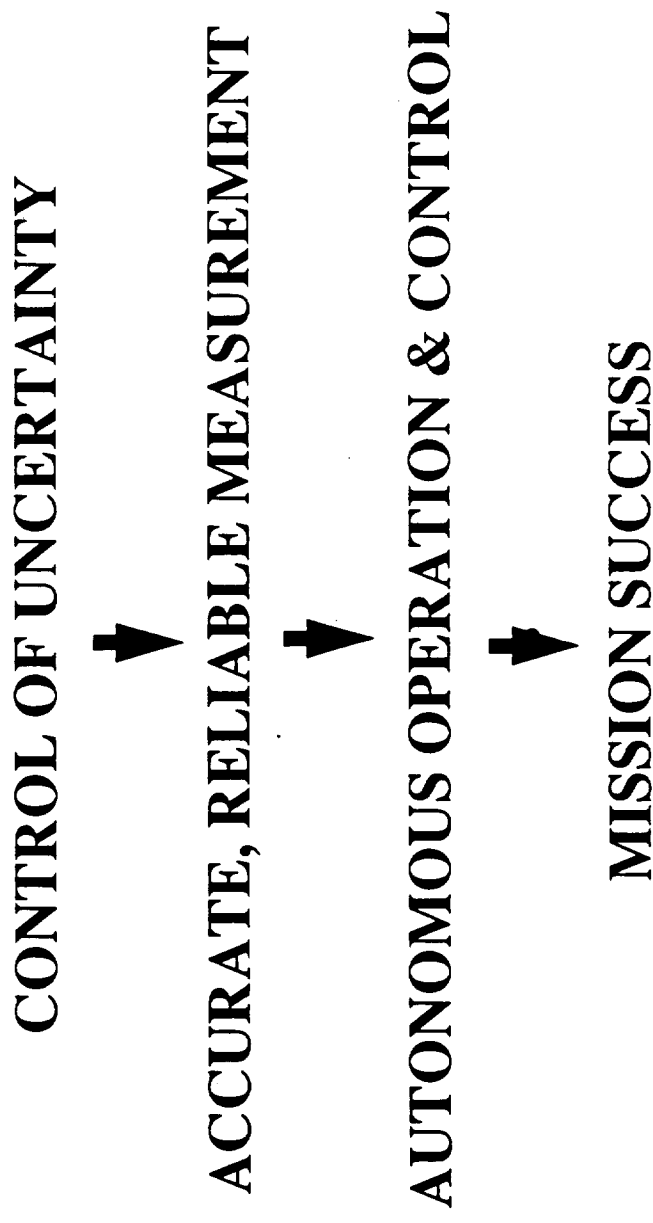
## **Metrology Challenge**

- Understand and control measurement uncertainties over long operational periods.
- Proper design, testing, operation, & calibration is needed for identification and control of uncertainty.
- Lower level functions of measurement processes must be automated.

## **Automated Operations**

- **To achieve the automation goals, the measurement and control system must have the following characteristics:**
  - **Architecture for on-board measurement audit and for system state and operating environment assessment.**
  - **Robustness to uncertain conditions.**
  - **Continued operation in the presence of faults and uncertainties.**
  - **High level object-oriented supervisory human interface.**





## The Three Axioms of Measurement

- Measurements only estimate the true value of the quantity being measured.
- Measurements are made to support decisions or establish facts. If not, the measurements are unnecessary.
- Every element of the measurement process that contributes to the uncertainty must be considered in estimating and containing the measurement uncertainty.

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## Measurement Quality Requirements Definitions

- **Measurement tolerance limits ( $L_+$ ):** the permissible range of values within which the true value lies.
- **Calibration interval (I):** the time within which uncertainty can be “guaranteed” to be within tolerance limits.
- **Measurement reliability (R):** the percent of measurement data that can be expected to be within the tolerance limits at the end of the “guarantee” period.

## Measurement Reliability

- The reliability goal of the operation or experiment.
- A design goal of the measurement hardware and process.
- The requirement that together with the out-of-tolerance rate of the measurement equipment ,  $\lambda$ , determines the calibration interval.

## **MTBOOT**

### **Mean-Time-Between-Out-of-Tolerance**

- Time interval for a measurement to go beyond desired uncertainty limits.
- $\text{MTBOOT} = -(\text{Usage hours per year}) / \ln R^*$
- $\text{MTBOOT} = 1 / \lambda_{\text{SYSTEM}}$

## MTBF vs. MTBOOT

### MTBF

Hardware

Reliability

Hard Failures

Detectable

### MTBOOT

Measurement

Confidence

Soft Failure

Undetectable

## Establishing Calibration Interval

- Measurement reliability is typically modeled by a negative exponential function of time and an estimate of out-of-tolerance rate,  $\lambda$ .
- Calibration interval,  $I$ , is determined for the target reliability,  $R^*$ , at the end-of-period.

$$R(t) = R_0 e^{-\lambda t}$$

$$I = \frac{R^*}{-\ln R_0 \lambda}$$

## **Contemporary Uncertainty Control Techniques**

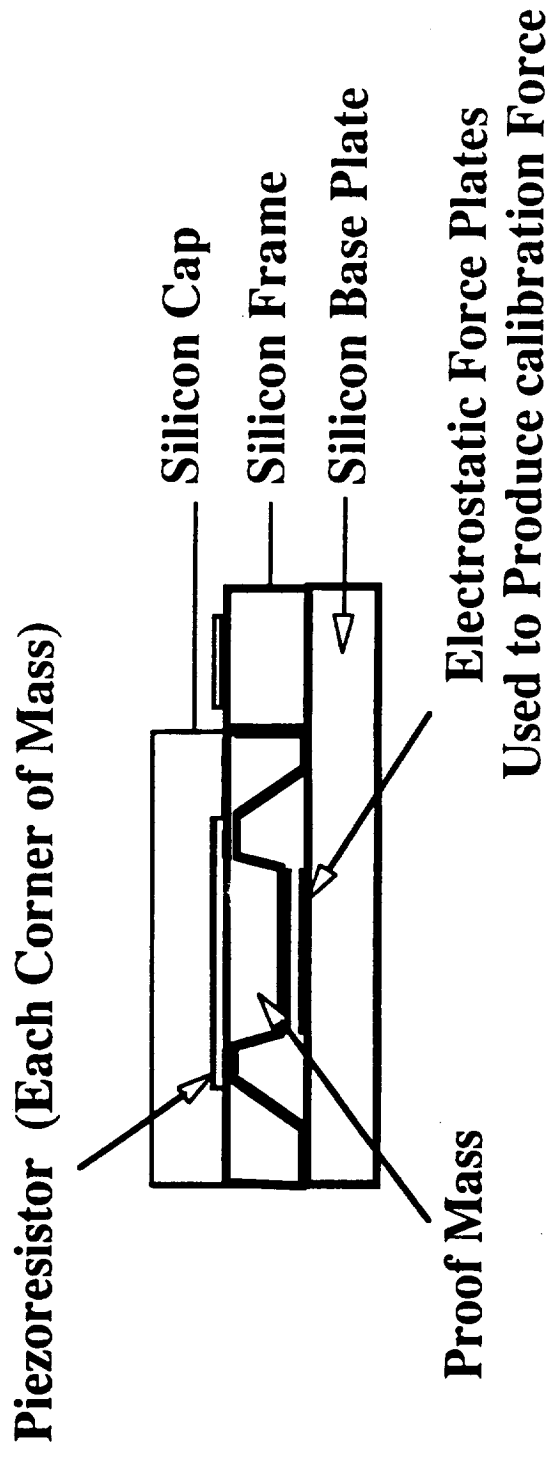
- **Sensors with the capability of in-position or self-calibration.**
- **Built-in redundant measurement circuitry to improve reliability.**
- **Alternative or multiple measurement and comparison techniques.**
- **Statistical Measurement Process Control.**
- **Corrections and adjustments via software.**

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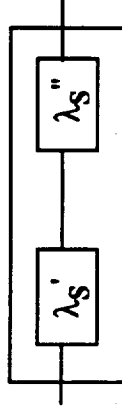
## Example of Built-In Calibration

### ACCELERATION SENSOR CHIP



# Reliability Improvement Through Redundancy

[  $\lambda_S = 0.02 \times 10^{-6}$ ;  $\lambda_B = 10 \times \lambda_S$ ; 10 year mission]

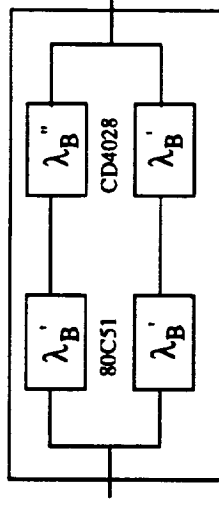


Series configuration  
of S-quality parts

$$R = R_1 \times R_2$$

$$= 0.9982 \times 0.9982 = .9964$$

Series-parallel  
configuration  
of B-quality parts



$$R = 1 - (1 - R_1 \times R_2)^2$$

$$= 1 - (1 - .9826^2)^2 = .9988$$

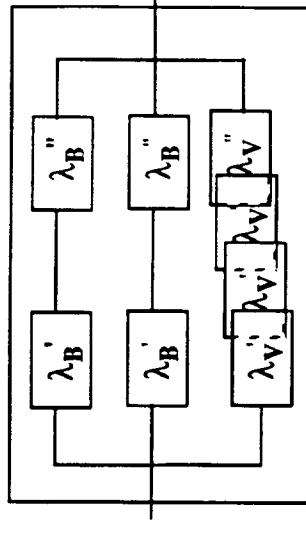
Series-parallel  
configuration  
of B-quality parts  
+ virtual  
measurement

$$R = 1 - (1 - R_1 \times R_2)^2 (1 - R_v^4)$$

$$= 1 - (1 - .9655^2)^2 (1 - .9988^4)$$

$$= .9998$$

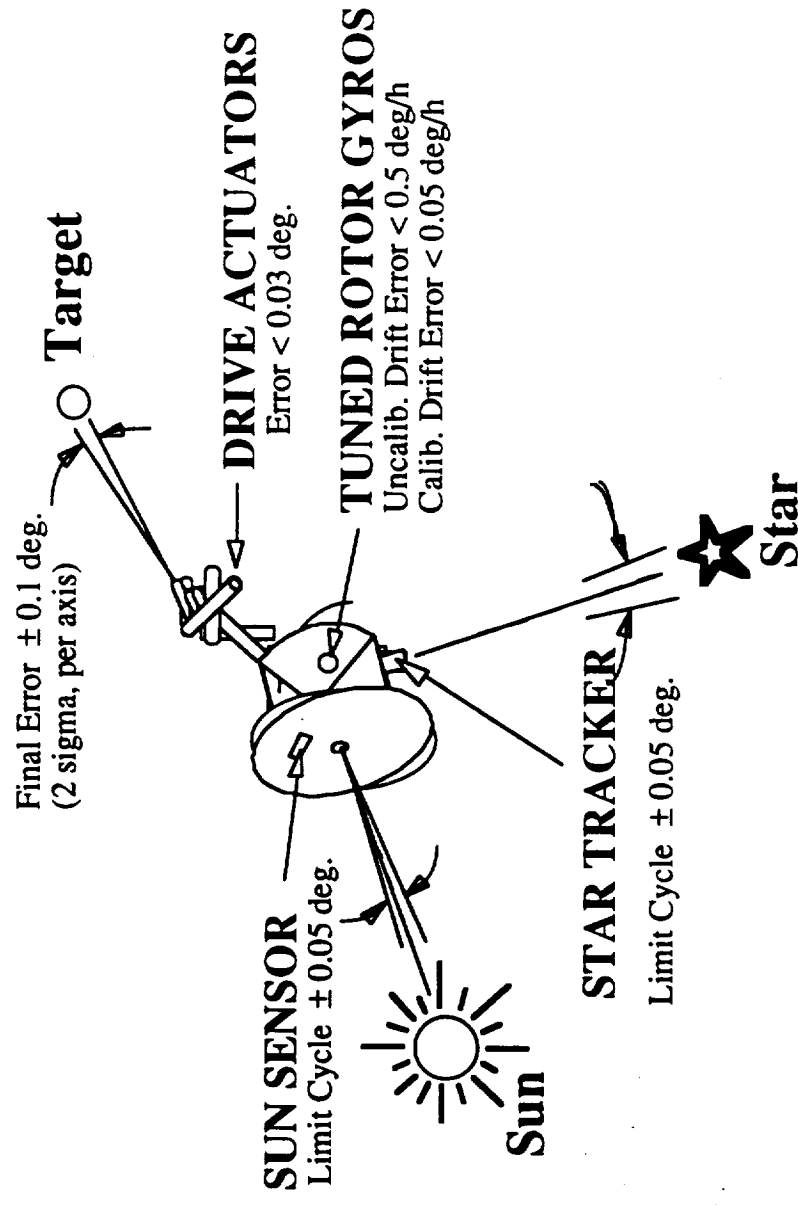
$$[R_v = .9952]$$



## **Virtual Measurements**

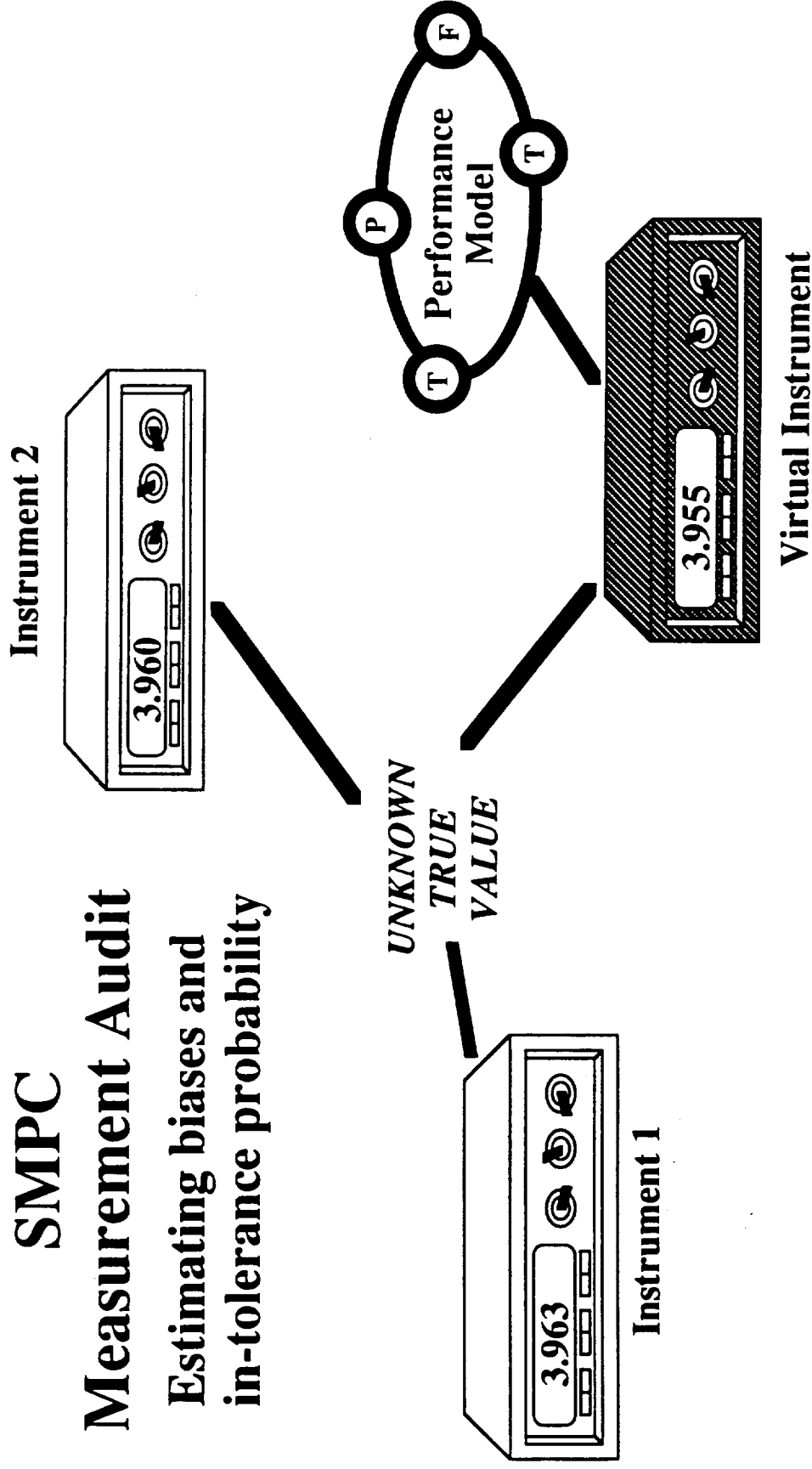
- **A calculated value of a measurement parameter based on a set of independent measurements linked by equipment performance models.**
- **Its utility is in measurement quality audits.**

# Example Voyager Spacecraft Attitude Measurements



# SMPC Measurement Audit

Estimating biases and  
in-tolerance probability



## Readings Matrix

- Operational readings:

$$Y_1 = 3.963; Y_2 = 3.960; Y_v = 3.955$$

- Difference Matrix

$$X_2 = Y_1 - Y_2 = 3.963 - 3.960 = .003$$

$$X_v = Y_1 - Y_v = 3.963 - 3.955 = .008$$

$$X_1' = Y_2 - Y_1 = 3.960 - 3.963 = -.003$$

$$X_v' = Y_2 - Y_v = 3.960 - 3.955 = .005$$

$$X_1'' = Y_v - Y_1 = 3.955 - 3.963 = -.008$$

$$X_2'' = Y_v - Y_2 = 3.955 - 3.960 = -.005$$

## Operational Bias Estimation

- Bias Estimate

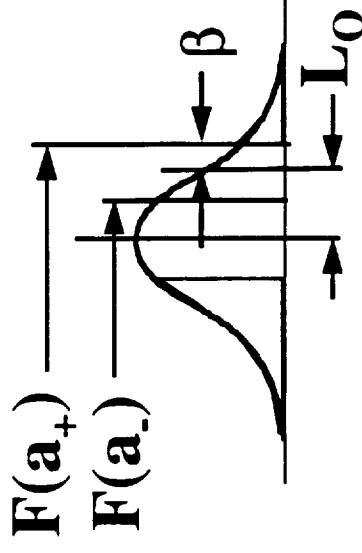
$$\beta_i = \frac{\sum X_i r_i^2}{1 + \sum r_i^2}$$

$$X_2 = Y_1 - Y_2 = 3.963 - 3.960 = .003$$

$$r = \text{dynamic accuracy ratio} = \sigma_0 / \sigma_i$$

## In-tolerance Probability Estimation

$$P_O = F(a_+) + F(a_-) - 1$$



$$a_{\pm} = \frac{\sqrt{1 + \sum r_i^2} \left[ L_0 \pm \frac{\sum X_i r_i^2}{1 + \sum r_i^2} \right]}{\sigma_0}$$



## In-tolerance Probability Estimation

- Pre-launch characterization:

$$L_0 = \pm 0.006 \quad \sigma_0 = 0.002 \quad r = 1.0$$

- Results:

$$Y_1 = 3.963 \quad \beta_1 = .0037 \quad P_1 = .98$$

$$Y_2 = 3.955 \quad \beta_2 = -.0043 \quad P_2 = .93$$

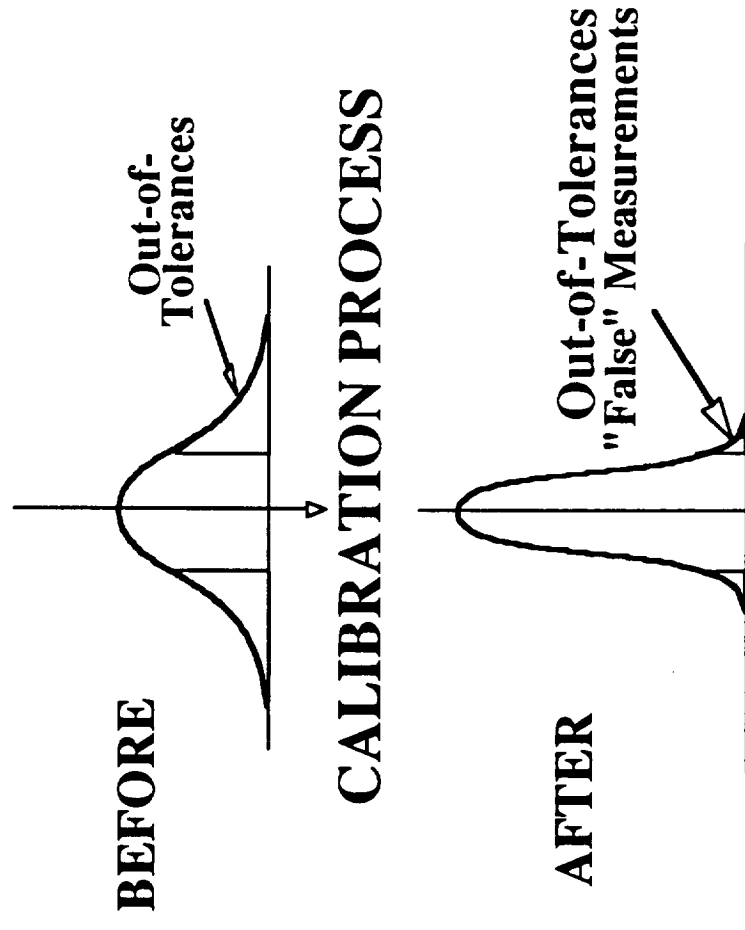
$$Y_v = 3.960 \quad \beta_v = .0007 \quad P_v = 1.00$$

## **SMPC Apply Under the Following Conditions**

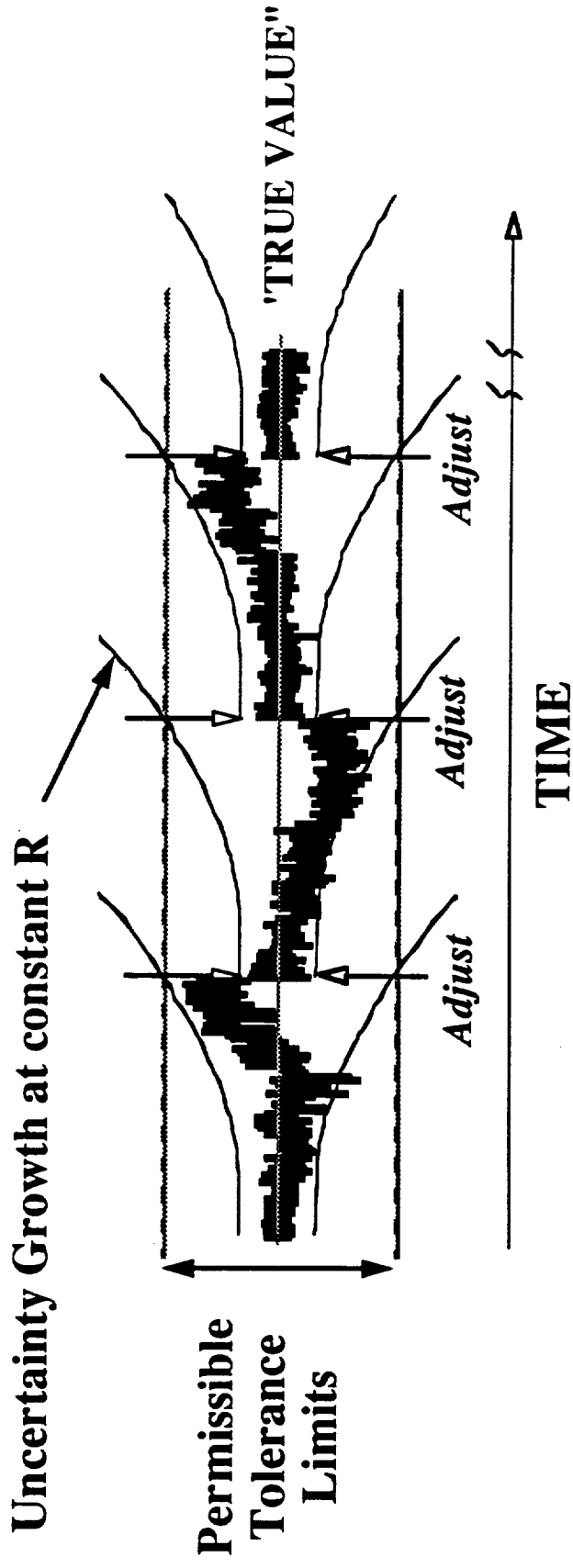
- The measurements in the set are statistically independent.
- Drift or other uncertainty growth characteristics of the set have been defined before deployment.
- The measurement processes in the set have been characterized, calibrated, and tested before deployment.

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## Uncertainty Control



# Uncertainty Growth Control



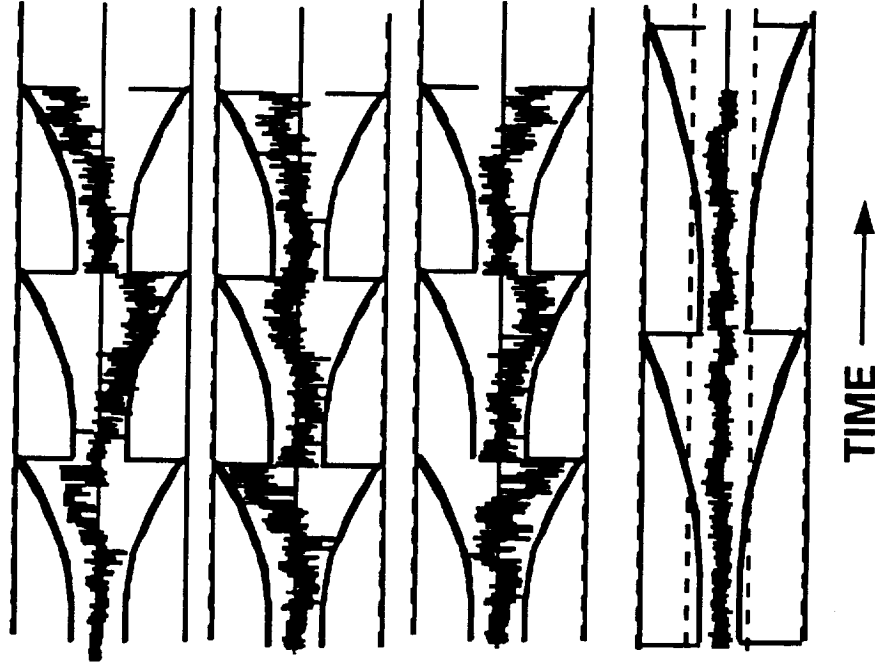
# Uncertainty Control With Multiple Sensors & SMPC

Instrument 1

Instrument 2

Virtual Instrument

Measurement  
Estimate



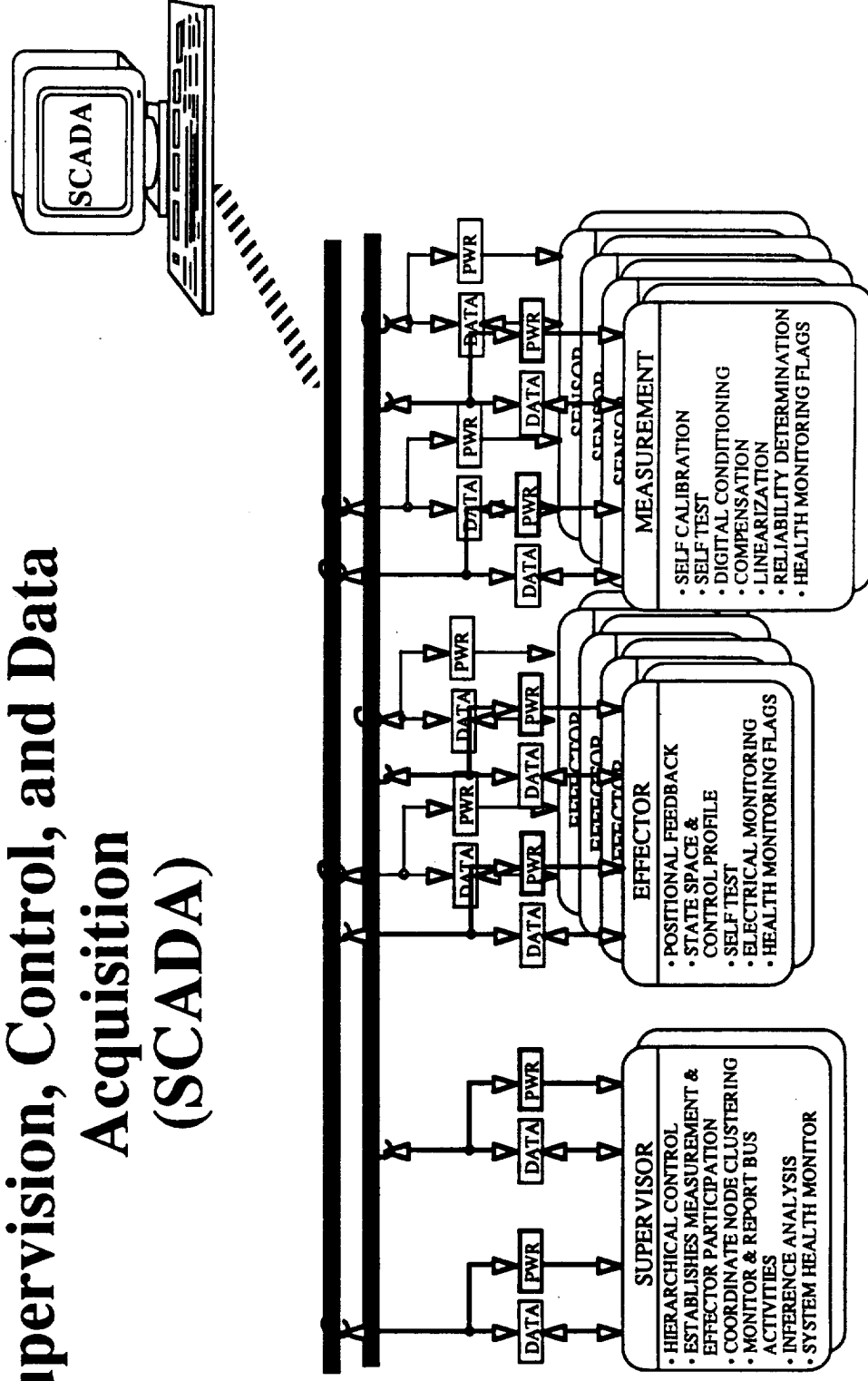
## **System Design Postulates**

- **A large system, produced by expanding the dimensions of a small system, does not behave like the small system.**
- **A complex system that works, has invariably evolved from a simple system that worked.**

## **System Development Methodology**

- **Build from reusable proven elements.**
- **Careful control of interface and communication between modules (appropriate coupling strategy).**
- **Architecture of hierarchical object-oriented modules with multi-path, self-regulative and prioritized peer-to-peer communications.**
- **Concurrent development and thorough module testing.**

# Supervision, Control, and Data Acquisition (SCADA)





## **Summary**

- **A system approach to spaced-based measurement processes covering:**
  - **Mission and operational requirements for success**
  - **Measurement process quality considerations**
  - **Application of MTBOOT and measurement reliability as a design goal**
  - **Reliability improvement through redundancy**
  - **The concept of “virtual” measurement**
  - **Measurement uncertainty control and audit by SMPC methods**

## **Summary (Cont'd)**

- **Application of contemporary micromachined structures to self-calibrating sensors**
- **System development methodology**
- **A system architecture for automated on-board measurement audit, system state and operating environment assessment, with minimum human involvement**

## **Conclusions**

- **Future space missions present metrology challenges that require new approaches for solution.**
- **Long duration and high measurement reliability requirements require careful system design.**
- **Measurement performance must be a design requirement.**
- **Evaluations of measurement reliability and out-of-tolerance-rate need to be part of the development process.**

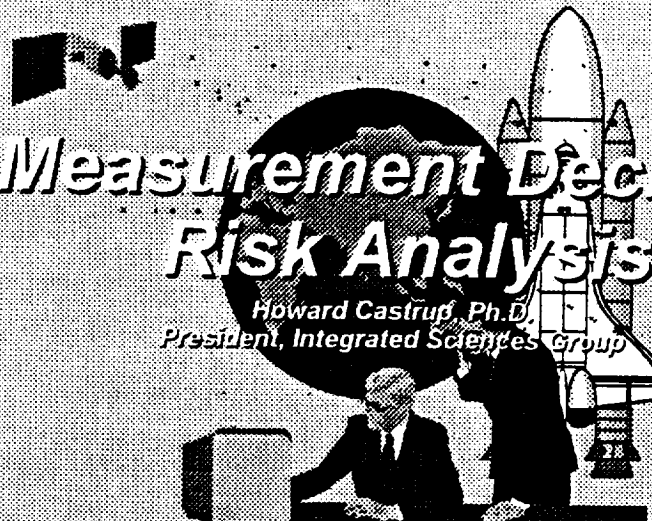
## **Conclusions**

**(Cont'd)**

- **Calibrations and characterizations are needed at various levels of measurement process integrations.**
- **Calibration labs need to be part of this total process.**
- **Measurement quality audit methodology needs to be formalized, part of the system design, and automated.**

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*Measurement Decision Risk Analysis*



# ***Measurement Decision Risk Analysis***

*Howard Castrop, Ph.D.  
President, Integrated Sciences Group*



**16th Annual NASA Metrology & Calibration Workshop**



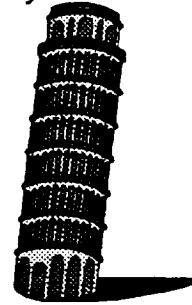
## *Measurement Decision Risk Analysis*

### **Measurement Decision Risk Analysis**

- *End Item Utility vs. Measurement Accuracy*
- *Cost of Accuracy vs. Cost of Low Utility*
- *Total Life Cycle Cost Optimization*

### **Uncertainty Growth Control**

- *Periodic Calibration / Testing*
- *Statistical Measurement Process Control*



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## **Measurement Decision Risk Analysis**

- **End Item Utility vs. Measurement Accuracy**
  - Determine the relationship between performance and utility.
  - Determine the relationship between performance and attribute (parameter) values.
  - Link attribute values to utility.
- **Cost of Accuracy vs. Cost of Low Utility**
  - Predict utility based on attribute value distributions.
  - Determine the "cost" of the predicted utility (*performance cost*).
  - Determine the cost of achieving the attribute distributions.
- **Total Life Cycle Cost Optimization**
  - Balance life cycle costs against performance cost.

## **Uncertainty Growth Control**

- **Periodic calibration / Testing**
  - Uncertainty grows with time elapsed since calibration or test.
  - Control uncertainty growth with periodic calibration or testing.
- **Statistical Measurement Process Control**
  - Use measurement results to evaluate measuring parameters.
  - Control uncertainty growth statistically.

# *Measurement Decision Risk Analysis*



## **Part I**

# **Measurement Decision Risk Analysis**



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## **Measurement Decision Risk Analysis**

- ☐ End item Utility vs. Measurement Accuracy
- ☐ Cost of Accuracy vs. Cost of Low Utility
  - Analyze total accuracy Life Cycle Cost.
  - Add Performance Cost to LCC.



## *Measurement Decision Risk Analysis*

### **Utility vs. Measurement Accuracy**

■ *Performance and Utility*

■ *Performance and Attribute Values*

■ *Attribute Values and Utility*

*Attribute Tolerances*

*Calibration and Testing*

*Uncertainty and Risk*

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### **Utility vs. Measurement Accuracy**

#### **□ Performance and Utility**

- ➔ How useful is a given level of performance?

#### **□ Performance and Attribute Values**

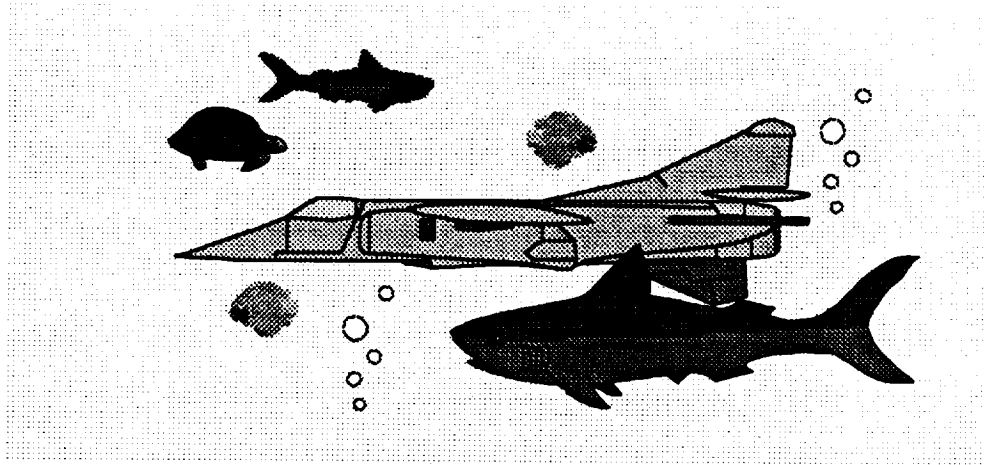
- ➔ How are performance and attribute values related?

#### **□ Attribute Values and Utility**

- ➔ Can attribute values be linked to utility?
- ➔ If so, what are limits that bound high vs. low utility?
- ➔ What is the role of calibration and testing in ensuring compliances with tolerances? In ensuring high utility?
  - ✓ What is the relationship between measurement uncertainty and decision risk?
  - ✓ How does decision risk impact utility?
  - ✓ How does uncertainty impact utility?

## *Measurement Decision Risk Analysis*

### **Performance and Utility**



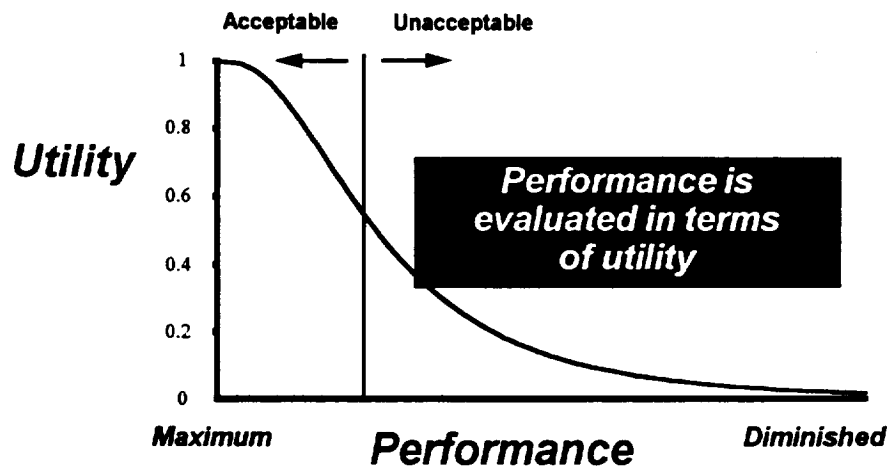
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## **Performance and Utility**

- ❑ **High Performance Doesn't Automatically Mean High Utility**
- ❑ **Utility Depends on Context**

## *Measurement Decision Risk Analysis*

### **Performance and Utility**



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## **Utility vs. Performance**

### **□ The Utility of Performance**

- ➔ Performance (e.g., engine thrust) corresponds to utility.
- ➔ 100,000 lbs of thrust is not especially useful if the load is 10,000,000 lbs.
- ➔ The utility of performance is context sensitive.

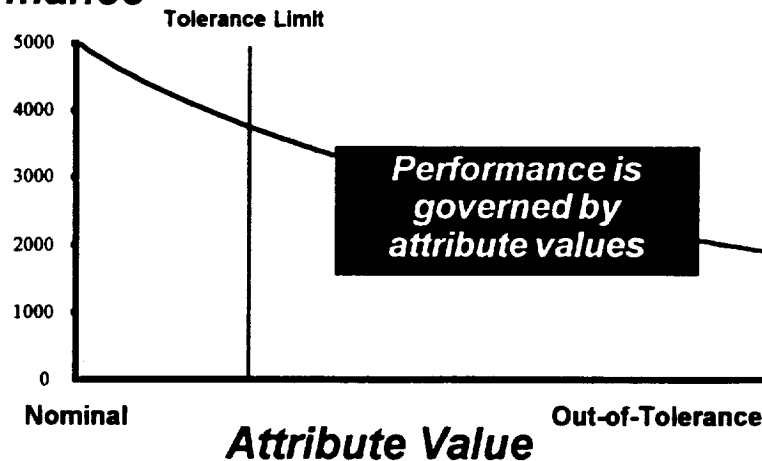
### **□ Performance Limits**

- ➔ Limits that bound acceptable vs. unacceptable performance correspond to limits that bound high vs. low utility.

## *Measurement Decision Risk Analysis*

### **Performance vs. Attribute Value**

#### **Performance**



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## **Performance vs. Attribute Value**

### **Functional Dependence**

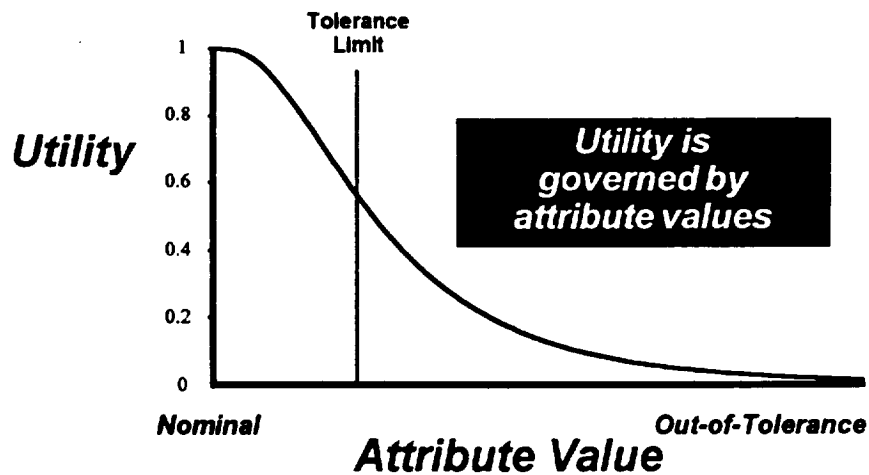
- ➔ The performance of an end item is functionally dependent on the values of its measurable parameters or attributes.
- ➔ E.g., the detection range of a radar is dependent on the detector sensitivity, the antenna gain, etc.

### **Tolerance Limits**

- ➔ Tolerance limits bound acceptable vs. unacceptable attribute values. These values should correspond to acceptable vs. unacceptable performance.

## *Measurement Decision Risk Analysis*

### **Utility vs. Attribute Value**



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## **Utility vs. Attribute Value**

### **□ Functional Dependence**

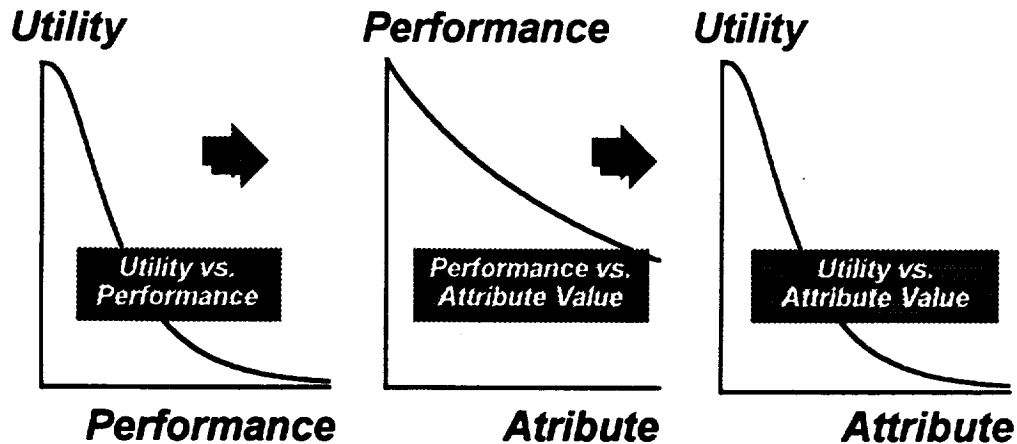
- ➔ If end item utility depends on end item performance, and ...
- ➔ End item performance depends on attribute values, then ...
- ➔ End item utility depends on attribute values.

### **□ Tolerance Limits Revisited**

- ➔ Limits that bound acceptable vs. unacceptable attribute values should correspond to limits that bound high vs. low utility.

## *Measurement Decision Risk Analysis*

### **Link Utility to Attribute Value**



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## **Link Utility to Attribute Value**

### **□ Establishing the Link**

- ➔ Transpose from the *Utility vs Performance* and the *Performance vs Attribute Value* curves to form a *Utility vs Attribute Value* curve.

### **□ Using the Link**

We want to know how the values of the attributes we're designing, building and testing relate to the utility of the systems they belong to.

- ➔ Determine what degree of attribute value containment corresponds to a given level of utility.
- ➔ Determine the cost benefit of this level of utility.
- ➔ Determine what it costs to achieve the attribute value containment.
- ➔ Balance this cost against the benefit of the utility gained by the attribute value containment.

**More will be said on this later.**

## *Measurement Decision Risk Analysis*

### **Link Utility to Attribute Tolerances**

#### **Salient Points:**

- *Attributes at or near nominal / design values correspond to high utility.*
- *Tolerances can be established to confine attributes close to nominal values.*
- *Tolerances are “tools” for ensuring high utility.*
- *Calibration and testing are done to ensure that attributes are within tolerances.*

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## **Why Test or Calibrate Attribute Values?**

- **Basic Premise:**
  - ➔ End item nominal or design points correspond to maximum performance and, therefore, to maximum utility.
  - ➔ Attribute values that stay close to these points correspond to high utility.
  - ➔ Attributes that stray too far from these points correspond to low utility.
- **Applying Tolerances**
  - ➔ If tolerance limits are established on the basis of utility, then ...
  - ➔ tolerance limits can be used as tools for ensuring utility.
- **Calibration and Testing**
  - ➔ Testing is done to ensure end item compliance with tolerances, i.e., to ensure utility.
  - ➔ Calibration is done to:
    - ✓ Ensure that test system attributes comply with their tolerances.
    - ✓ Control uncertainties in tooling and manufacturing.

## *Measurement Decision Risk Analysis*

### ***Link Utility to Calibration and Testing***

#### **A Logical Conclusion:**

- *Since calibration and testing are done to ensure that attributes are within tolerance, then calibration and testing are done to ensure high utility.*

#### **A Natural Question:**

- *Can the cost of calibration and testing be balanced against the benefit of improved utility?*

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## **Linking Utility to Calibration and Testing**

### **□ A Summary of Findings to this Point**

- Low utility corresponds to high cost.
- If tolerances are meaningful, in-tolerance attributes should correspond to high utility.
- Therefore, in-tolerance attribute values should correspond to low cost.
- Calibration and testing ensure that attribute values are in-tolerance.
- This means that calibration and testing ensure high utility.
- Therefore, calibration and testing save money.
- But calibration and testing cost money.

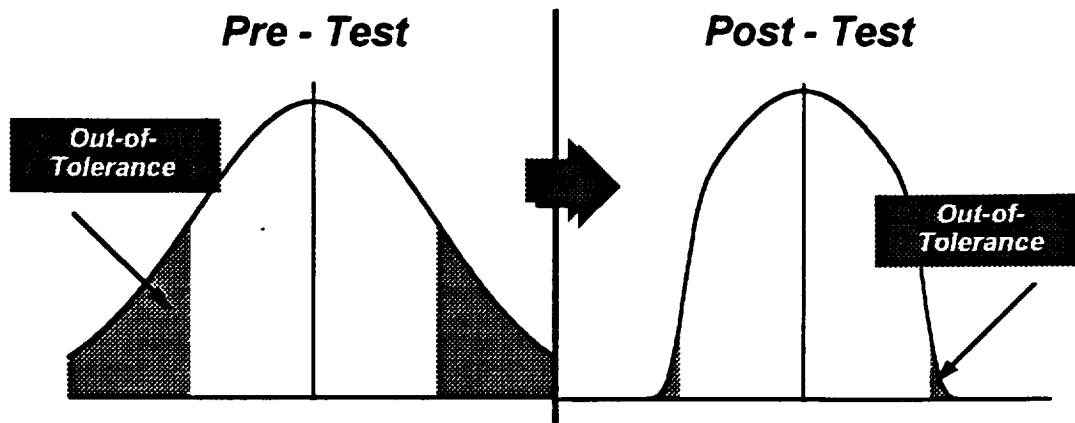
### **□ The Key Question**

**Can the cost of calibration and testing be traded off against the cost benefit of high utility?**



## *Measurement Decision Risk Analysis*

**Keep Attributes Close to Nominal  
by Controlling Uncertainty**



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## **Controlling Uncertainty**

### ☐ **Motivation for Measurement**

- Whether testing an end item, calibrating a test system or measuring a component, measurements are made to make decisions or obtain information.

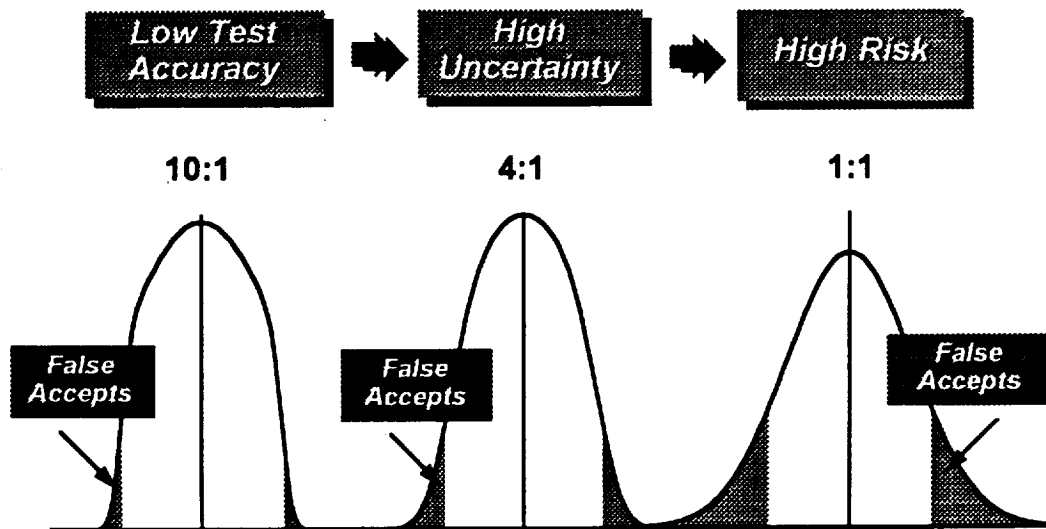
### ☐ **Decision Process**

- Is the measured value acceptable?
- If the measured value is used (in design or manufacturing), will the outcome be successful?

### ☐ **Outcome of a Measurement**

- Unacceptable measured values are rejected.
- The chance of employing "low utility" attributes is, hopefully, reduced.

## Measurement Decision Risk Analysis



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## Measurement Decision Risk

### □ Decision Risk vs. Accuracy

- The probability of making a wrong decision based on measurement results is called *measurement decision risk*.
- Decisions made from accurate measurements are likely to be more correct than decisions based on inaccurate measurements.

### □ Principal Types of Risk

- False Accept Risk
  - ✓ The probability that out-of-tolerance attributes will be measured as in-tolerance.
- False Reject Risk
  - ✓ The probability that in-tolerance attributes will be measured as out-of-tolerance.

## *Measurement Decision Risk Analysis*

**Reduce Costs by Investing in  
Measurement Accuracy**

**A new equation:**

*High Uncertainty = High Risk = Low Utility*

**= High Cost**

*Accurate Measurements = Low Uncertainty = High Utility*

**= Low Cost**

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## **Risk Consequences**

Low Accuracy (High Uncertainty) = High Risk

### **❑ False Accept Risk**

- Leads to more out-of-tolerance attributes being accepted.
- Lowers the overall utility of attributes in use.
- Factors into the Performance Cost equation.

### **❑ False Reject Risk**

- Leads to unnecessary rework of compliant attributes.
- Factors into the Operating Cost equation.

### **❑ Cost Implications**

- Higher accuracy means
  - ✓ Better utility
  - ✓ Reduced operating expenses
  - ✓ Lower cost

## *Measurement Decision Risk Analysis*

***Answer the key question***

**But How Accurate is Accurate Enough?**

- *Higher accuracy costs money.*
- *Can we calculate return on investment?*
- *Where's the break even point?*

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## **Return to the Key Question**

Can the cost of calibration and testing be traded off against the cost benefit of high utility?

Obviously, we need to

- **Determine Performance Cost**
  - The cost of less than maximum utility.
- **Determine the Cost of Accuracy**
  - The total life cycle cost of a measurement capability.

*Measurement Decision Risk Analysis*  
**Cost of Accuracy vs. Cost of Low Utility**

■ *Performance Cost (Cost of low Utility)*

■ *Cost of Measurement Accuracy*

■ *Total Cost Optimization*

*Utility Analysis*

*Risk Analysis*

*Cost Analysis*

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## **Accuracy Cost vs. Performance Cost**

### **□ Performance Cost**

- The cost of low utility.
- "Encounter" probabilities.
- Successful outcome probabilities.
- Cost of unsuccessful outcomes.

### **□ Accuracy Cost**

- Total life cycle cost of measuring systems

### **□ Total Cost Optimization**

- Add Performance Cost to the life cycle cost equation.

## *Measurement Decision Risk Analysis*

### **Performance Cost**

#### **The Cost of Diminished Utility:**

- Failed missions.
- Wasted hardware.
- Injury or loss of life.
- Recall and retrofit.
- Penalties
- Warranty expenses
- Legal fees
- Lost income
- Loss of reputation

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## **Performance Cost Analysis**

What does it cost when missions fail, hardware is wasted, human casualties occur, end items need to be recalled and reworked, fines are levied for poor performance, warranties need to be honored, lawsuits are filed, income is lost from inactive systems, or reputation suffers?

- **Cost of "useless" hardware**
  - ➔ In the event that hardware is used, what does it cost if Utility = 0?
- **Probability of a hardware application ...**
  - ➔ Threat encounter
  - ➔ Critical application
  - ➔ etc.
- **Probability of a successful outcome if Utility = 1**
  - ➔ If systems perform as intended, what is the probability that the outcome will be successful?
    - ✓ Stable orbit
    - ✓ Successful re-entry
    - ✓ etc.

## *Measurement Decision Risk Analysis*

### **Decision Risk Analysis Process**

#### **1. Utility Analysis:**

- *Relate utility to performance.*
- *Relate performance to attribute values.*
- *Relate utility to attribute values.*
- *Relate utility to Performance Cost.*
- *Relate attribute values to Performance Cost.*

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## **The Decision Risk Analysis Process**

### **□ Utility Analysis**

- ➔ **Model utility vs. attribute value.**
- ➔ **Estimate probability of application.**
- ➔ **Estimate probability of successful outcome, given maximum utility.**
- ➔ **Estimate cost of unsuccessful outcome (Performance Cost).**
- ➔ **Model Performance Cost vs. attribute value.**

## *Measurement Decision Risk Analysis*

### **Decision Risk Analysis Process**

#### **2. Risk Analysis:**

- *Relate attribute value distributions to measurement accuracy.*
- *Analyze measurement decision risk.*

#### **3. Cost Analysis:**

- *Relate measurement decision risk to calibration / testing Life Cycle Cost.*
- *Compare Life Cycle Cost vs. Performance Cost.*
- *Minimize total cost.*

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## **The Decision Risk Analysis Process**

- ❑ **Perform measurement decision risk analysis**
  - Construct a "pre-measurement" attribute value statistical distribution.
  - Analyze False Accept and False Reject risks.
  - Construct a "post-measurement" attribute value statistical distribution.
  - Compute the expected Performance Cost for the post-measurement distribution.
- ❑ **Perform the total cost analysis**
  - Calculate the total life cycle cost for calibration / test systems.
  - Compare life cycle cost against the expected Performance Cost.
  - Evaluate the return on investment.
  - Repeat the process until the utility cost benefit is equal to life cycle costs. This is the break even point.



## *Measurement Decision Risk Analysis*

### **Life Cycle Cost**

#### **The Cost of Measurement Accuracy:**

##### **Acquisition**

Procurement  
Eval and Verification  
Inventory  
Unit Price  
Start Up  
Shipping  
Time

##### **Training**

Operator  
Calibration  
Maintenance  
Engineering  
Instructor

##### **Ownership**

Operation  
Calibration  
Maintenance  
Repair  
Warranty

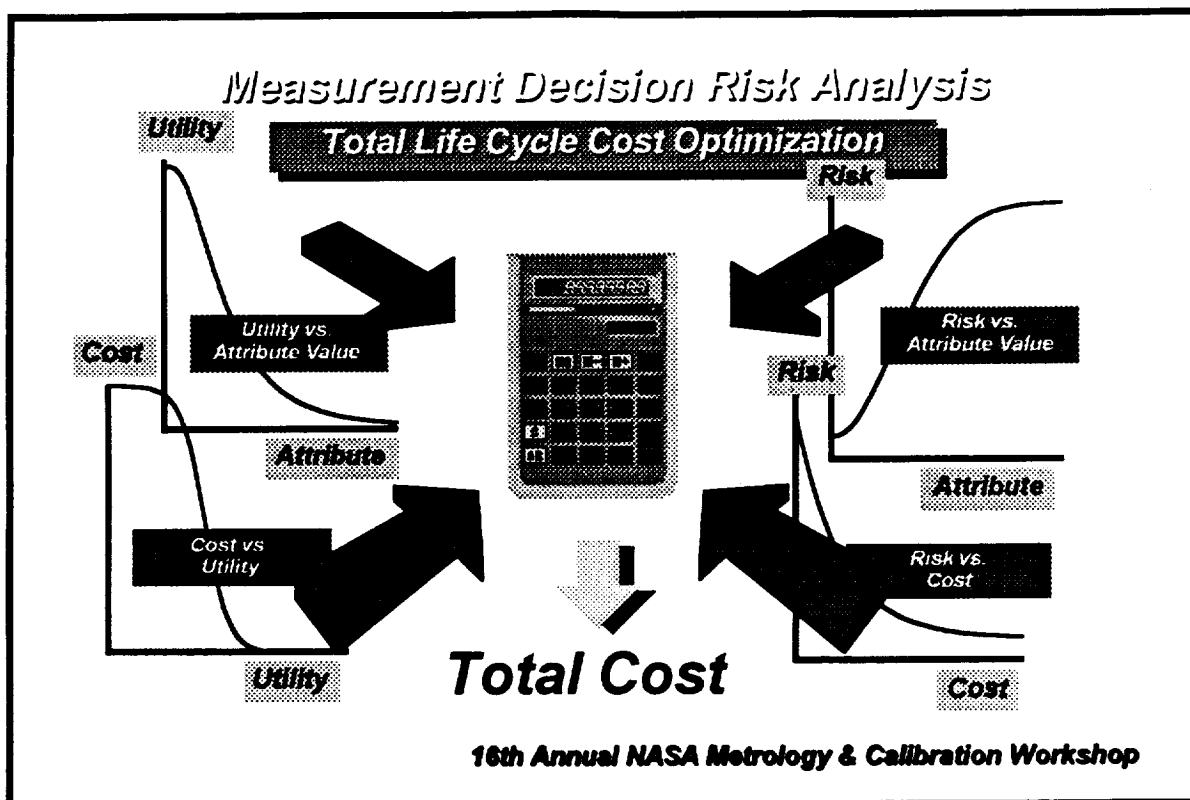
##### **Disposal**

Closeout  
Shipping  
Data Closure  
Refurbishment  
Waste Disposal  
Resale

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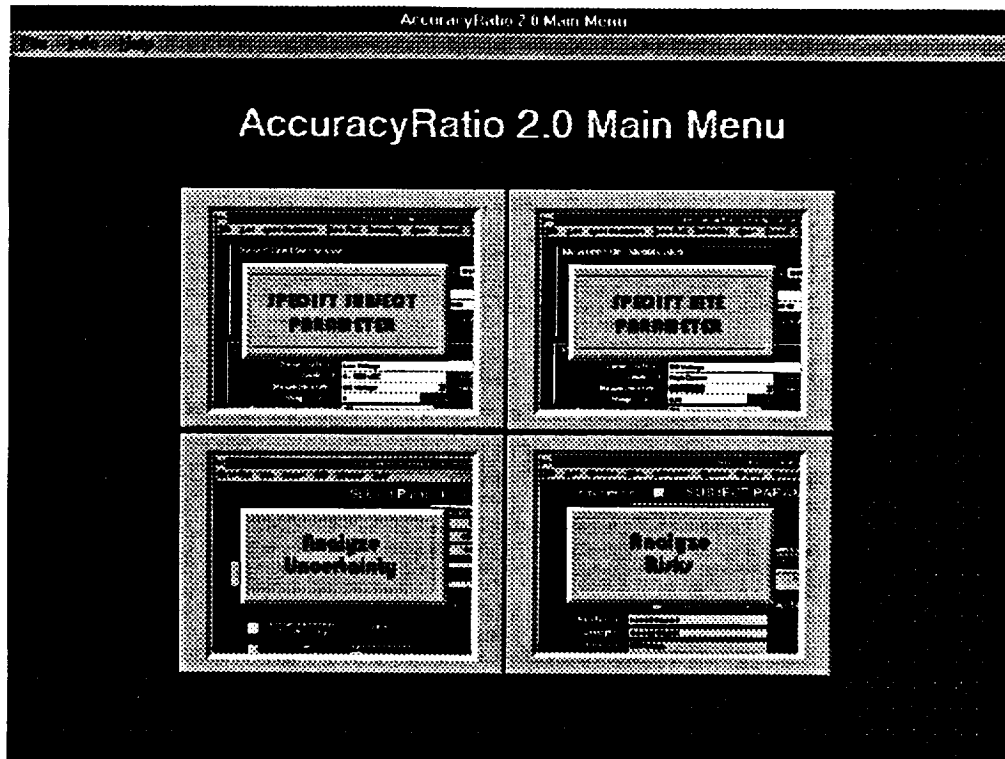
## **Life Cycle Cost Analysis**

The cost of accuracy is determined through an analysis of the total life cycle cost of the measuring system.



## Total Life Cycle Cost Optimization

- ☐ Include Performance Cost as a Life Cycle cost element.
- ☐ Evaluate the cost of not procuring on the same footing as the cost of procurement.
- ☐ Evaluate the cost of not improving accuracy in the same way as the cost of improving accuracy.



## Measurement Decision Risk Process

### Specify Subject Parameter

- ☐ Identify the artifact or device being measured (subject unit) and the parameter being measured (subject parameter). Enter administrative, identification and technical data as appropriate.

### Specify Measuring Parameter

- ☐ Identify the artifact or device performing the measurement and the measuring parameter. Enter administrative, identification and technical data as appropriate.

### Analyze Uncertainty

- ☐ Enter data needed to determine the measurement process uncertainty. Analyze uncertainty and select appropriate options.

### Analyze Risks

- ☐ Establish a baseline measurement risk and compute the risks involved in measuring the subject parameter with the MTE parameter. Select options for storing data and analysis results and for printing reports and plotting graphics.

Subject Parameter Specification Template

---

### Subject Unit Identification

Manufacturer	Gargano Market Inc.	Model Number	1513	Serial Number	25478863415
Description	Bathroom Scale	Class Code	1234L32	P/Z ID Number	1
Control Number	15	Location	Bakersfield	Building	39
Dept. Name	Showering and Showering	Dept. No.		Staff	Howard
System	Weight Control	Subject Unit Cal/Test Recall Cycle 12 Months			

---

### Subject Parameter Identification

Parameter Name	Weight				
Qualifier 1	Spring Action	Qualifier 2	Analog Meter		
Measurement Area	Mass	Nominal Units	lb		
Range or Scale	0	Lowest	300	Highest	
Threshold or Tolerating Value	275	% In-Tolerance at Test or Cal: 78.0000			
Subject Parameter Cal/Test Interval: 12 Months					

---

### Subject Parameter Tolerances

	Fixed Offset	N. of Periods	% of Scale	Offset Units	Computed Offset
Upper Offset	0	1.0	0	lb	-0.000
Lower Offset	0	1.0	0		0.000

Tolerance Units: ☐ J (JANIS) ☐ Single-Sided Upper ☐ Single-Sided Lower ☐ Symmetric Tolerances

Offset Display: ☐ Nominal Units ☐ Offsets

## Subject Parameter Specification

### Subject Unit Identification

- ☐ Different users may require unique sets of specifications for the same manufacturer model.
- ☐ Note the recall interval. This is the interval for recalling the item for periodic test or calibration.

### Subject Parameter Identification

- ☐ In-tolerance percentages may vary from application to application (i.e., from user to user).
- ☐ Note the calibration interval. This is the interval between periodic tests or calibrations of the subject parameter. It may differ from the recall interval.
- ☐ For subject parameters, the % In-Tolerance at Test or Cal refers to the end-of-period (EOP) in-tolerance percentage.

### Subject Parameter Tolerances

- ☐ Tolerances can be two-sided, single-sided upper, single-sided lower, symmetric or asymmetric. Tolerances may be called out in different units than nominal values.
- ☐ Subject parameter tolerances are used to define subject parameter bias uncertainty and to bound acceptable parameter values.

Measuring Parameter Specification Template

File Edit View Help Print Data File Database Data Control System Help

### Measuring Unit Identification

Manufacturer: High Priced Enterprises Model Number: 10 Serial Number: 4  
 Description: Physician's Office Scale Class Date: 1234567 P/S Number: 312  
 Control Number: 17 Location: Century City Building: Plaza Room: 1422  
 Dept. Name: Feelgood's Office Dept. No.: 14225 User: Feelgood  
 System: Pre-examination Subject Unit Cal/Test Reset Cycle: 48 Months

### Measuring Parameter Identification

Parameter Name: Weight  
 Qualifier 1: Lever Action Qualifier 2: Standard Weight Set  
 Measurement Area: Mass Nominal Units: lb  
 Range or Scale: 250 Lower: 300  
 Nominal or Reading Value: 205.0 % In-Tolerance at Test or Cal: 95.0000  
 Subject Parameter Cal/Test Interval: 48 Months

### Measuring Parameter Tolerances

	Fixed Offset	% of Reading	% of Scale	Offset Units	Computed Offset
Upper Offset:	0	0	0.35	lb	1.05450
Lower Offset:	0	0	0.35		-1.05450

Tolerance Units: ☐ Two-Sided ☐ Single-Sided Upper ☐ Single-Sided Lower ☐ Symmetric Tolerances  
 Offset Display: ☐ Nominal Units ☐ Offset Units

## Measuring Parameter Specification

### Measuring and Test Equipment (MTE) Identification

- ☐ As with subject units, different users may require unique sets of specifications for the same manufacturer model.

### Measuring Parameter Identification

- ☐ Again, in-tolerance percentages may vary from user to user.
- ☐ For the MTE parameter, the % In-Tolerance at Test or Cal refers to the average-over-period (AOP) in-tolerance percentage.

### Subject Parameter Tolerances

- ☐ Tolerances can be two-sided, single-sided upper, single-sided lower, symmetric or asymmetric. Tolerances may be called out in different units than nominal values.
- ☐ Tolerances are used, along with in-tolerance percentage, to compute limits of measurement bias uncertainty.

Measurement Process Uncertainty Analysis System

### Subject Parameter Information

Subject Parameter:

Subject Parameter Nominal Value:  lb

Computed Mean Value:  lb

Mean Deviation from Nominal:  lb

☒ Measurement Process Uncertainty

☐ Combined Uncertainty

Process Uncertainty:  lb

Uncertainty Component	Estimated Limits of Error	Units	Level of Confidence (%)	Standard Deviation
<input checked="" type="checkbox"/> Measuring Parameter Bias Uncertainty	0.756	lb	70.0000	0.729
<input checked="" type="checkbox"/> Random Measurement Error	1.500	lb	95.000	2.079
<input checked="" type="checkbox"/> Measuring Parameter Resolution Error	0.050	lb	95.000	0.025
<input checked="" type="checkbox"/> Subject Parameter Resolution Error	0.500	lb	95.000	0.250
<input checked="" type="checkbox"/> Operator Error	0.250	lb	95.000	0.125
<input checked="" type="checkbox"/> Sensor Intrusion Error	0.000	lb	95.000	0.000
<input checked="" type="checkbox"/> Subject Parameter Fluctuation Error	1.000	lb	95.000	1.530
<input checked="" type="checkbox"/> Ancillary Equipment Error	0.250	lb	95.000	0.303

## Uncertainty Analysis

- ❑ Measurement Process Uncertainty sources:
  - ➔ Random error - short term fluctuations during measurement.
  - ➔ Measurement resolution error - both subject and MTE parameter.
  - ➔ Operator error - parallax, etc.
  - ➔ Sensor intrusion error - effect of measurement system on subject parameter values.
  - ➔ Subject parameter fluctuation error - intermediate term fluctuations in the measured quantity.
  - ➔ Ancillary equipment or effects error - bias uncertainty due to ancillary sources (e.g., temperature, vibration, radiation, etc.)
- ❑ Estimate each in turn. Include in the total measurement process uncertainty. Combine with measurement bias uncertainty.
- ❑ Either factor out or compensate for estimated deviations from nominal.

**Data Entry Template**

Report/Export Save Help F4 F5 F6

---

**Subject Parameter - Weight**

Nominal Value:  in   
 Range or Scale:  to

**MTE Parameter - Weight**

Reading or Graphic:  in   
 Range or Scale:  to

---

**Measurement Data Entry**

OK Cancel **Desired Units**

Measured Values in   
 Deviations from Nominal in   
 Enter Data:

No.	Measured Value	Deviation from Nominal
1	204.9	9.9
2	205.1	10.1
3	208.3	13.3
4	204.6	9.6
5	200.0	13.0
6	203.2	9.2
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		

---

**Computed Statistics**

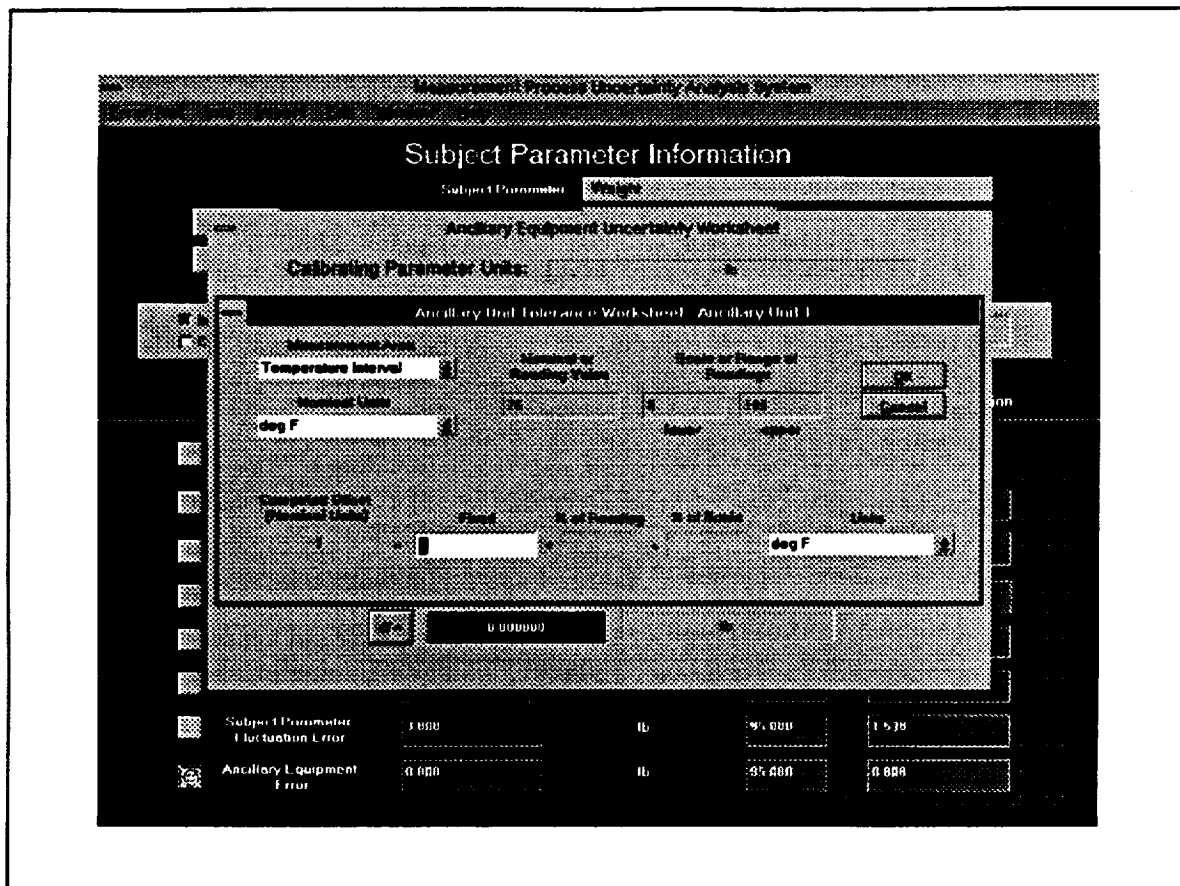
	Units	in
Sample Size		6
Sample Mean		205.7
Mean Deviation		10.7
Standard Deviation		2.0
Confidence Level (%)		95
Student's t		2.0
Confidence Limit		4.1

**Data Histogram**

# Observed:  # Measured Values:  # Deviations:

## Analyze Random Uncertainty

- ☐ Specify units for measurements and for deviations from nominal.
- ☐ Enter either a sample of measured values or deviations from nominal.
- ☐ Compute relevant random measurement uncertainty statistics. Employ methods that are statistically valid and are generally accepted, such as the new ISO/NIST guidelines.



## Ancillary Sources of Error

- ☐ Measuring and subject parameter values may be influenced by ancillary factors:
  - ➔ Temperature
  - ➔ Vibration
  - ➔ Stray radiation
  - ➔ etc.
- ☐ Identify each ancillary factor and indicate ranges of values that may pertain during measurement.



Measurement Process Uncertainty Analysis System

Subject Parameter Information

Subject Parameter: Weight

Ancillary Equipment Uncertainty Worksheet

Calibrating Parameter Units

ID Number	Ancillary Parameter	Tolerance Offset	Units	% In-Tolerance	Interaction Contribution*	Standard Deviation
1	Temperature	1.0000	deg F	95	25	0.000000
2		0.0000		0.0000	0.000000	0.000000
3		0.0000		0.0000	0.000000	0.000000
4		0.0000		0.0000	0.000000	0.000000
5		0.0000		0.0000	0.000000	0.000000

Buttons: Cancel OK Help

\* Cal Parameter Units / Acc. Equip. Units

Compute Ancillary Source Standard Deviation

Buttons: OK Cancel

Result: 0.000000

Subject Parameter Fluctuation Error: 1.0000 IB 95.000 1.530

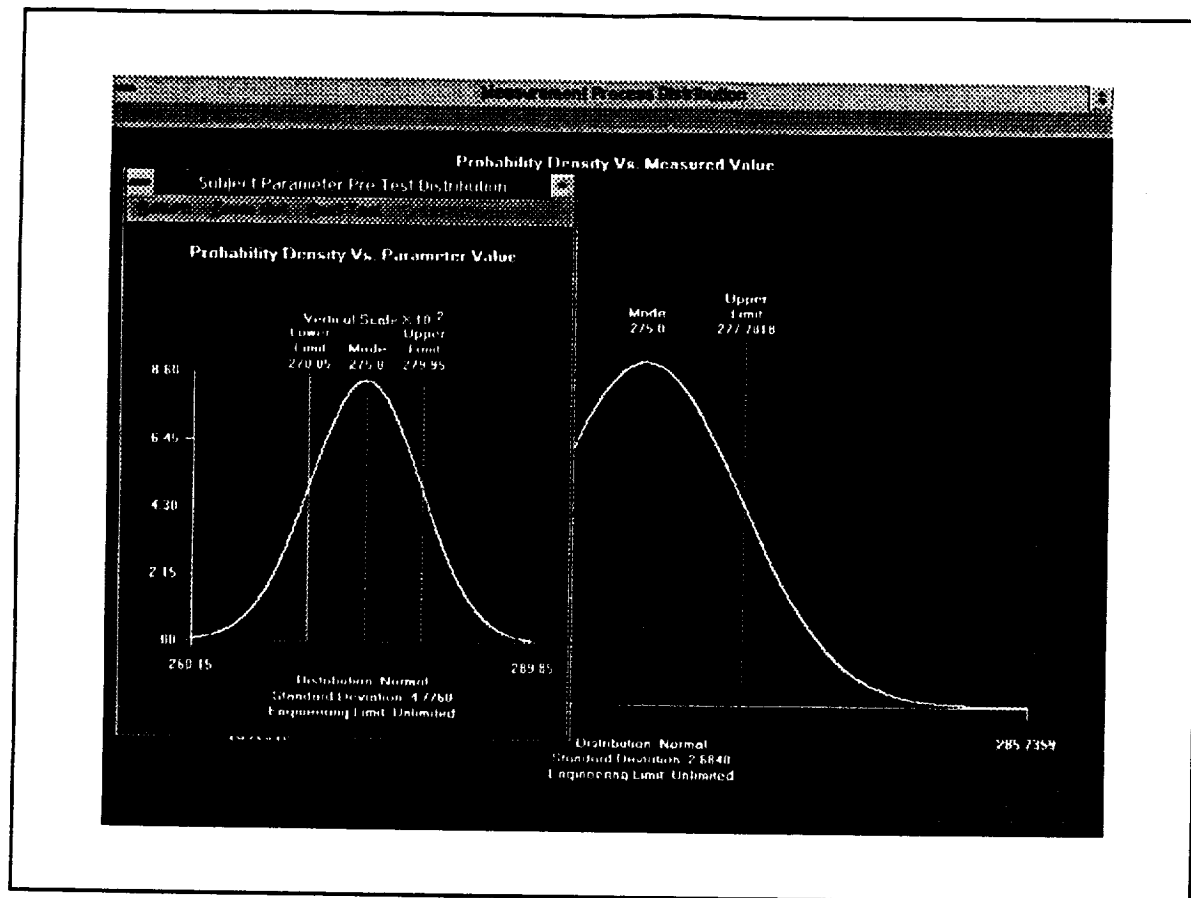
Ancillary Equipment Error: 0.000 IB 95.000 0.000

## Ancillary Sources of Error (cont.)

- ☐ For each ancillary error source indicate either an in-tolerance percentage or a confidence level for the range (limits) of ancillary values.
- ☐ Compute the standard deviation for each source.
- ☐ Combine the ancillary source standard deviations into an estimate of their contribution to overall measurement process uncertainty.







## Impact of Uncertainty on Risks

- Although the nominal accuracy ratio is 5:1, the ratio of standard deviations is  $(4.78 / 2.68) = 1.78:1$ .
- Suppose an 85% measuring parameter in-tolerance is specified in the baseline.
  - ➔ Then the standard deviation of 2.68 corresponds to an 85% confidence limit of 3.86.
  - ➔ The ratio of this confidence limit to the subject parameter tolerance of 4.95 gives an equivalent accuracy ratio of 1.28:1. (Note that this is nearly equal to the 1.19:1 ratio computed by AccuracyRatio on the basis of false accept risk.)
  - ➔ This is considerably smaller than the nominal 5:1 accuracy ratio.

## Impact of Uncertainty on Risks (cont.)

*Measurement Decision Risk Analysis*



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## **Uncertainty Growth Control**

- ☐ Periodic Calibration / Test
- ☐ Statistical Measurement Process Control

*Measurement Decision Risk Analysis*

## **Measurement Uncertainty Growth Control**

■ *Measurement Uncertainty Growth*

■ *Measurement Reliability Analysis*

■ *Uncertainty Growth Control*

*Periodic Calibration and Testing*

*Statistical Measurement Process Control*

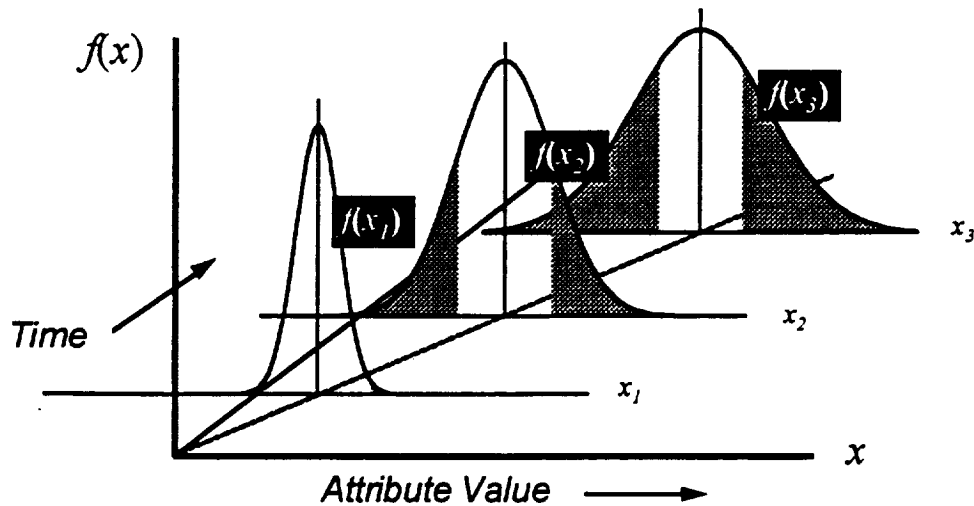
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## **Measurement Uncertainty Growth Control**

- **Measurement Uncertainty Growth**
  - Uncertainty Growth.
  - Uncertainty Growth Modeling.
- **Measurement Reliability Analysis**
  - Reliability Modeling.
  - Interval Prediction.
  - Post-implementation.
  - Pre-implementation.
  - Upcoming analysis technology.
- **Uncertainty Growth Control**
  - Periodic re-measurement
  - SMPC

## Measurement Decision Risk Analysis

### Measurement Uncertainty Growth



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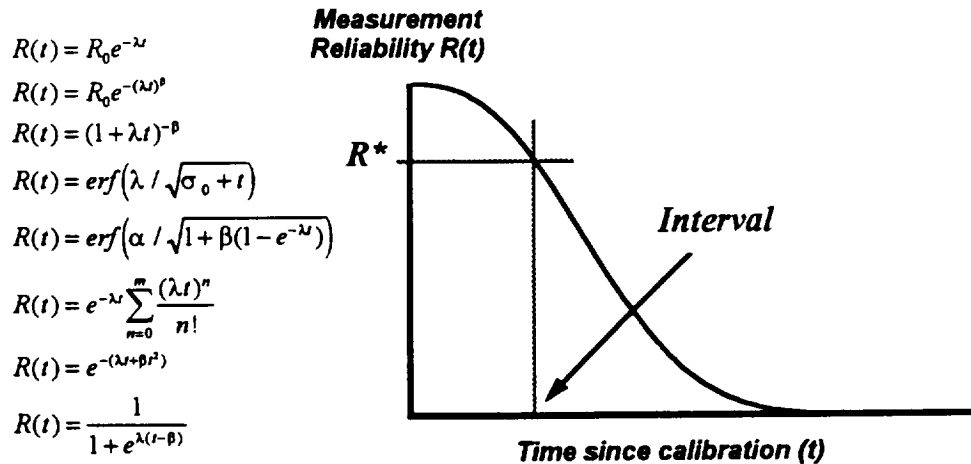
## Measurement Uncertainty Growth

- **As soon as a measured artifact leaves our hands, the uncertainty in its value begins to grow. This is due to**
  - Mathematical uncertainties involved in predicting drift.
  - Stresses encountered during use.
  - Other random and / or systematic effects.
- **Bias Error Distributions**
  - The uncertainty in the bias error (deviation from predicted values) is represented by statistical distributions.
- **Bias Error Uncertainty Growth**
  - The spread in bias error distributions grows with time.
  - The in-tolerance probability diminishes with time.
- **Utility Loss**
  - From before, we saw that keeping attributes within tolerance is synonymous with maintaining high end item utility.
  - If in-tolerance probability diminishes with time, then so does utility.



## Measurement Decision Risk Analysis

### Measurement Uncertainty Growth



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## Uncertainty Growth Modeling

### □ Reliability Modeling

- Measurement Reliability = In-tolerance probability.
- Since in-tolerance levels diminish with time, measurement reliability diminishes with time.
- The process is modeled mathematically.

### □ Interval Prediction

- An appropriate reliability model is selected.
- Historical data are used to determine the parameters of the model.
- The value of the reliability function is set equal to a "Reliability Target" ( $R^*$ ).
  - ✓  $R^*$  is an in-tolerance level that has been established as acceptable.
  - ✓  $R^*$  corresponds to acceptable false accept and false reject risks.
- The test / calibration interval corresponding to  $R^*$  is solved for.

## *Measurement Decision Risk Analysis*

### **Measurement Reliability Analysis**

#### **1. Post-Implementation:**

##### **Assemble history data:**

*Homogeneous groups  
Time since last service  
Condition received*

##### **Construct the measurement reliability time series:**

*Number calibrated/tested  
Number in-tolerance  
Resubmission time*

##### **Perform Maximum Likelihood Analysis:**

*Dog/gem filtering  
Reliability model selection  
Model fit to time series data*

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## **Measurement Reliability Analysis**

### **□ Post-Implementation**

- Historical data consist of a history of calibration / test results that indicate the in- or out-of-tolerance status of attributes as received for calibration or test (Condition Received).
- Data are organized into a Time Series and analyzed using *Maximum Likelihood Analysis*.
- Maximum likelihood analysis yields
  - ✓ An identification of the appropriate reliability model.
  - ✓ Maximum Likelihood Estimates (MLE) of reliability model parameters.
  - ✓ An identification of attributes with significantly low (dog) or high (gem) reliability.

## *Measurement Decision Risk Analysis*

### **Measurement Reliability Analysis**

#### **2. Design / Development:**

- **Three things make a spec:**
  - Tolerance limits*
  - Duration for which limits are applicable*
  - Probability that tolerance limits will be applicable for the specified duration.*
- **Assemble stability data:**
  - Number observed*
  - Number in-tolerance*
  - Duration*
- **Treat as calibration / test history:**
  - Construct the time series*
  - Perform maximum likelihood analysis*

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## **Measurement Reliability Analysis**

### **□ Pre-Implementation**

- Attribute stabilities are sampled or simulated during design and development.
- "Historical" data are assembled from sampled / simulated in- or out-of-tolerance conditions spread over time.
- Data are organized into a Time Series and analyzed using Maximum Likelihood Analysis.
- Maximum likelihood analysis yields
  - ✓ An identification of the appropriate reliability model.
  - ✓ Maximum Likelihood Estimates (MLE) of reliability model parameters.

## *Measurement Decision Risk Analysis*

### **Measurement Reliability Analysis**

#### **3. On the Horizon:**

##### **Current Methodology**

- ❑ *Model uncertainty growth indirectly.*
- ❑ *Construct time series based on attributes data.*
- ❑ *Model evolution of attributes data times series.*
- ❑ *Make no direct reference to attribute tolerances.*
- ❑ *Require 30 or more observations to achieve predictability.*
- ❑ *Are usually locked in to in- or out-of-tolerance judgements at time of calibration or test.*

##### **Emerging Methodology**

- ❑ *Directly model uncertainty growth.*
- ❑ *Use variables data (measured values).*
- ❑ *Model evolution of attribute distributions over time and usage.*
- ❑ *Permit tolerancing to achieve desired measurement reliability levels.*
- ❑ *Reach high confidence with less data.*
- ❑ *Automatically force consideration of the third spec requirement:*

*Probability that limits will be applicable for the specified duration.*

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## **Measurement Reliability Analysis**

### **❑ Current Methodology**

- **Reliability models are inferred from in- or out-of-tolerance (attributes) data. These data reflect an underlying uncertainty growth process.**
- **The evolution of the time series is mathematically modeled.**
- **30 or more observations are needed per time series.**
- **Tolerances are embedded in the data.**

### **❑ Emerging Methodology**

- **Uncertainty growth is modeled directly from measured attribute values.**
- **Trial tolerances can be imposed to see their impact on measurement reliability.**
- **Fewer observations are required to infer the uncertainty growth process.**

## *Measurement Decision Risk Analysis*

### **Uncertainty Growth Control**

#### **A Major Operating Cost Driver:**

- *Establish reliability targets.*
- *Analyze calibration / test intervals.*
- *Calibrate / test periodically*
- *Use SMPC.*

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## **Uncertainty Growth Control**

Controlling uncertainty growth is a major cost driver in test and calibration programs.

**Intervals that are too long generate excessive risks.**

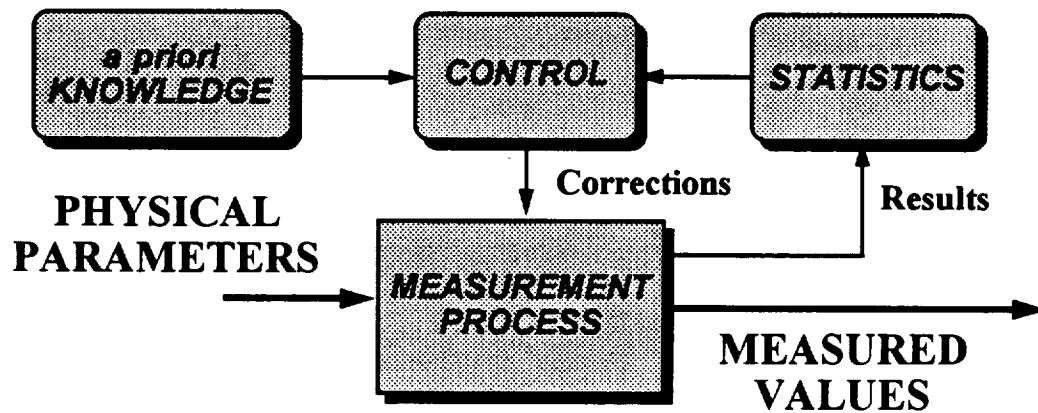
**Intervals that are too short generate excessive cost.**

Uncertainty growth is controlled in two ways:

- **Calibrate / Test Periodically**
  - ◆ **Establish Reliability Targets**
    - ✓ Analyze measurement decision risk to establish optimal reliability targets.
  - ◆ **Analyze Calibration / Test Intervals**
    - ✓ Obtain MLE model parameters and predict intervals that correspond to reliability targets.
  - ◆ **Calibrate / Test Periodically**
- **Apply Statistical Measurement Process Control**

## Measurement Decision Risk Analysis

### Statistical Measurement Process Control (SMPC)



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**Use *a priori* knowledge and measurement results to evaluate the accuracy of the measuring system along with the subject attribute.**

#### □ *A priori* Knowledge

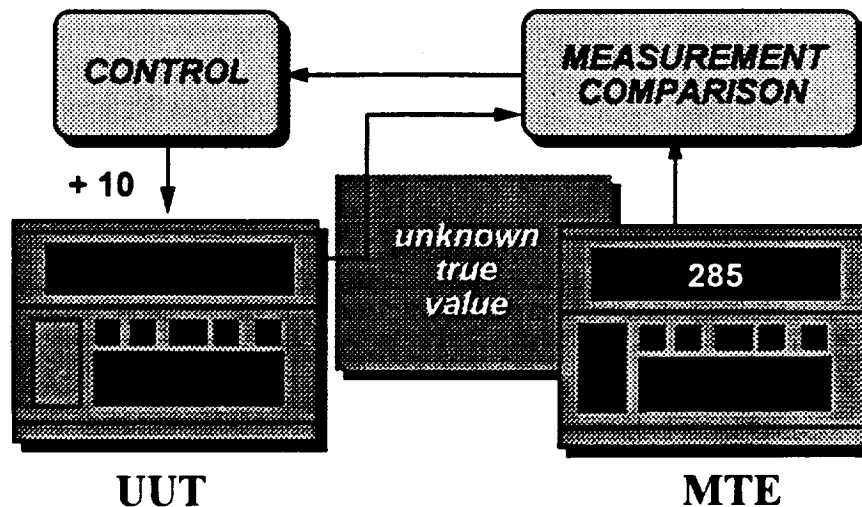
- Every measurement is approached with *some* up-front "knowledge" of accuracies...
  - ✓ Whether the measuring system is more accurate than the subject attribute.
  - ✓ A "history" of measurement results.
  - ✓ Some feel for measurement stability.
  - ✓ etc.

#### □ Statistical Analysis

- Use ISO/NIST methods to place *a priori* knowledge on a statistical footing.
- Treat measurement results (readings, outputs, nominal values, etc.) as random variables that estimate the "true" value of the measurand.
- Combine *a priori* knowledge and measurement results to obtain statistical best estimates:
  - ✓ Subject and measuring attribute biases, confidence limits and in-tolerance probabilities.

## *Measurement Decision Risk Analysis*

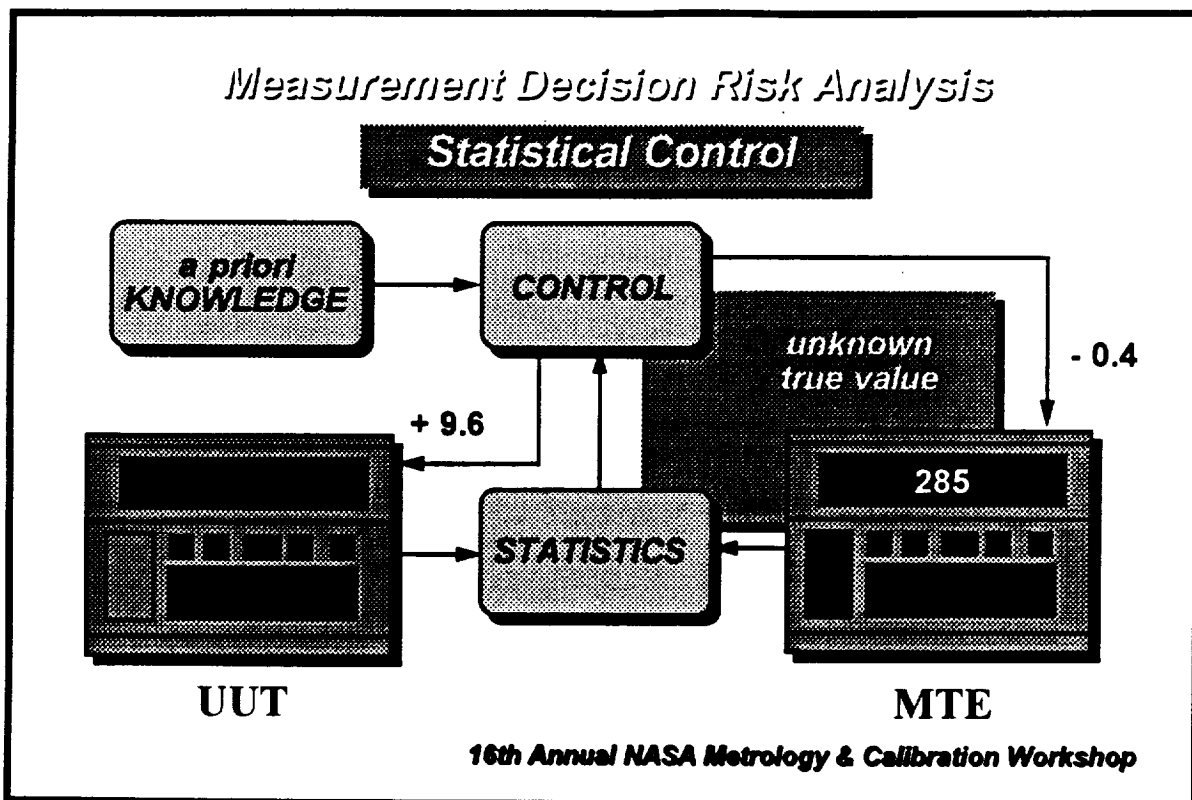
### **Non-Statistical Control**



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## **Non-Statistical Control**

- ❑ The measuring system (Measuring and Test Equipment) is treated as an “authority.”
- ❑ Corrections are applied to the subject attribute (Unit Under Test).
- ❑ The UUT is judged in- or out-of-tolerance by the MTE.



## Statistical Control

- ☐ The measuring MTE is treated as just another measuring system.
- ☐ Corrections are applied to both the UUT and the MTE.
- ☐ The UUT and the MTE are judged in- or out-of-tolerance by the set of measurement results and a *priori* knowledge.



## *Measurement Decision Risk Analysis*

### **How SMPC Works**

- *Use a priori knowledge of MTE and UUT accuracies.*
- *Calibrate the UUT(s) with the MTE(s).*
- *Intercompare measured values statistically.*
- *Estimate in-tolerance probabilities for UUT(s) and MTE(s).*
- *Estimate biases (errors) for UUT(s) and MTE(s).*
- *Apply correction factors to UUT(s) and MTE(s).*





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## **The SMPC Procedure**

## *Measurement Decision Risk Analysis*

### ***a priori "Knowledge"***

#### **Approach the Measurement Process with...**

-  *Calibration / test historical data.*
-  *"Reasonable" assumptions based on engineering analysis.*
-  *Known uncertainty growth rate and time since prior calibration / test.*
-  *Virtual measurement.*

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## ***a priori Knowledge***

Something that accompanies all measurements.

- ☐ **Calibration / Test History**
  - Bias uncertainty growth rates.
- ☐ **Engineering Assumptions**
  - Inherent stabilities and physical attribute limitations.
  - Measurement process stability.
- ☐ **Time Since Calibration / Test**
- ☐ **Virtual Measurement**
  - Bias projections based on drift or other characteristics.

SMPC Analysis System

SMPC Scratch Pad

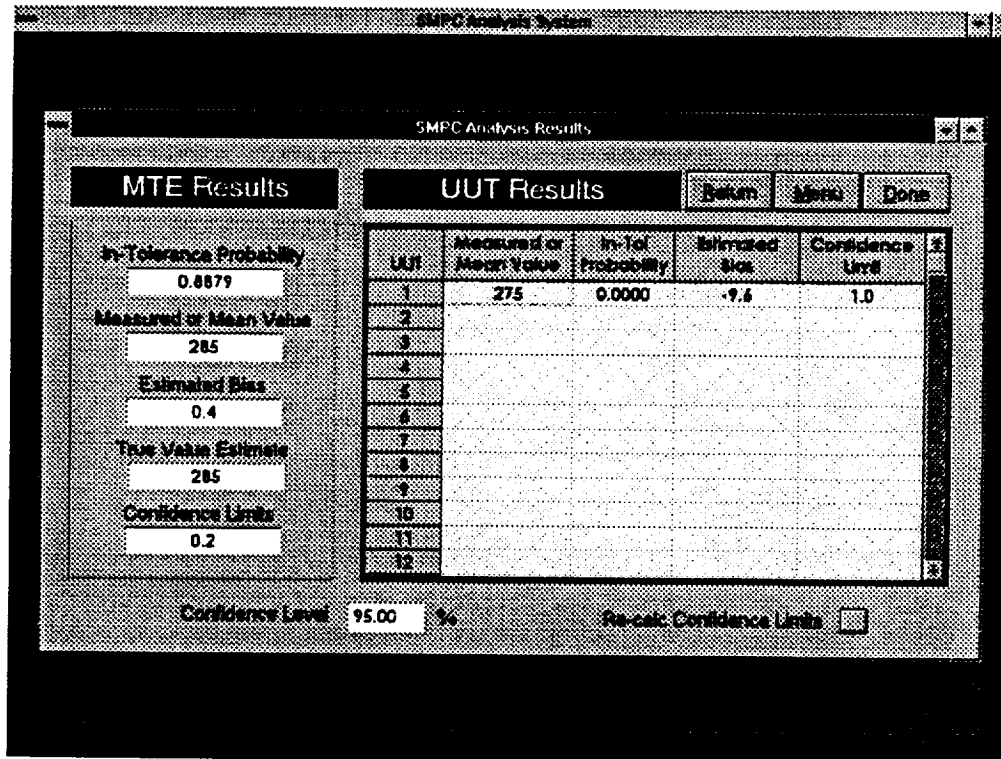
File Edit View Options Window Help

Input Data:

UUT #	UUT Name	Meas. or Mean Value	Tolerance Class	% In-Tol	Sample Size	Sample Std Deviation	UUT Error
0	Feelgood's Scale	285	1	95	1		
1	Howard's Scale	275	5	95	1		
2							
3							
4							
5							
6							
7							
8							
9							
10							
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## Simple Case - One MTE / One UUT

- ❑ Make a single measurement with each device.
- ❑ Assemble and tabulate what is known.
  - Measurement results.
  - *A priori* "knowledge."
    - ✓ Tolerance limits: Taken from manufacturer specs.
    - ✓ Confidence levels: "Knee-jerk" 95% confidence often used in statistics problems.



## SMPC Results

- In-tolerance probabilities:
  - Given the measurement results and the *a priori* knowledge, SMPC is used to compute in-tolerance probabilities for both UUT and MTE:
    - ✓ UUT: In-tolerance probability = 0.0000
    - ✓ MTE: In-tolerance probability = 0.8879
- Estimated biases:
  - Non-SMPC approach: The UUT has a -10 lb bias.
  - SMPC approach:
    - ✓ The UUT has a -9.6 lb bias
    - ✓ The MTE has a +0.4 lb bias.
- Confidence limits:
  - MTE: Measured value - 0.4 lb  $\pm$  0.2 lb
  - UUT: Measured value + 9.6lb  $\pm$  1.0 lb

Note that, although no external standards were used, an in-tolerance probability, a bias estimate and confidence limits were obtained for the MTE as well as for the UUT. The 88.79% in-tolerance probability for the MTE is less than the *a priori* 95% level.

SMPC Analysis System

SMPC Scratch Pad

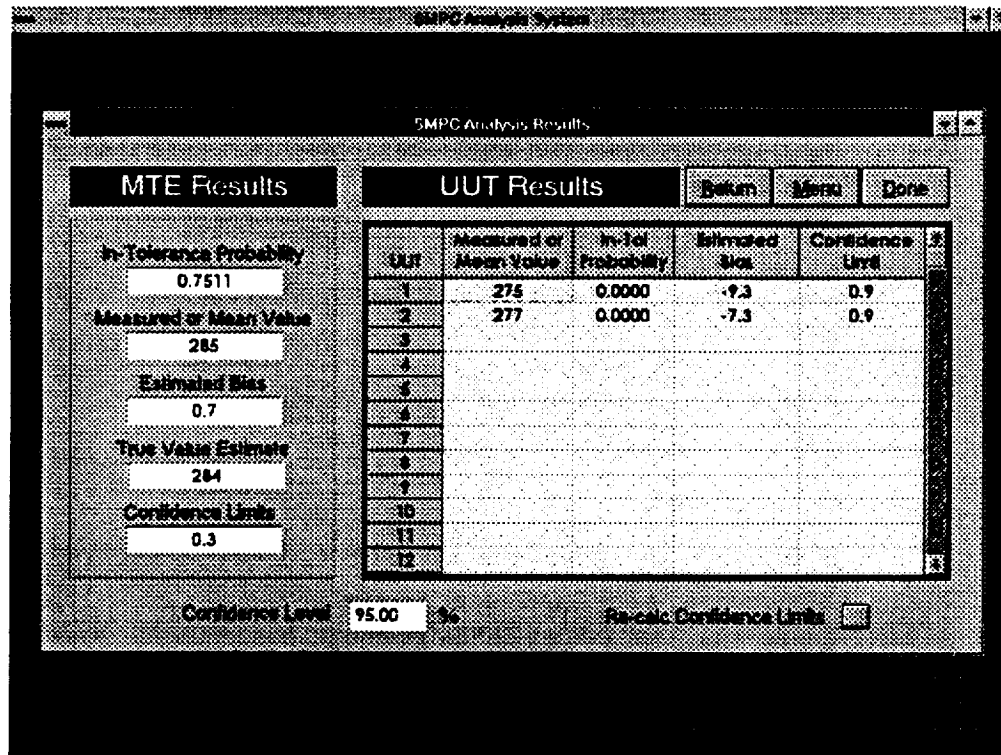
File Edit Report/Print Window Help

Input Data:

UUT #	UUT Name	Mean or Mean Value	Tolerance Other	% In-Tol	Sample Size	Sample Std Deviation	UUT Error
0	Feelgood's Scale	285	1	95	1		
1	Howard's Scale	275	5	95	1		
2	Bob's Scale	277	5	95	1		
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## Now add a second UUT ...

- ☐ Make a single measurement with the MTE and each UUT.
- ☐ Assemble measurement results and *a priori* knowledge.



## SMPC Results

Adding a 2nd UUT changes the picture. The 2nd UUT sort of agrees with the first, and, like the 1st, disagrees with the MTE. However, the MTE is still *a priori* "more accurate" than either UUT. What can be inferred from all this?

- In-tolerance probabilities:
  - The revised estimate for the MTE in-tolerance probability is lowered by the new results. At the same time, because the 2nd UUT agrees with the 1st, the in-tolerance probability estimate for the 1st UUT is increased.
- Estimated biases:
  - The estimated bias for the first UUT is now smaller, while the estimated bias for the MTE is larger.
- Confidence limits:
  - The confidence limits for the first UUT's bias estimate have shrunk, while the confidence limits for the MTE bias estimate have expanded.

SMPC Analysis System

SMPC Scratch Pad

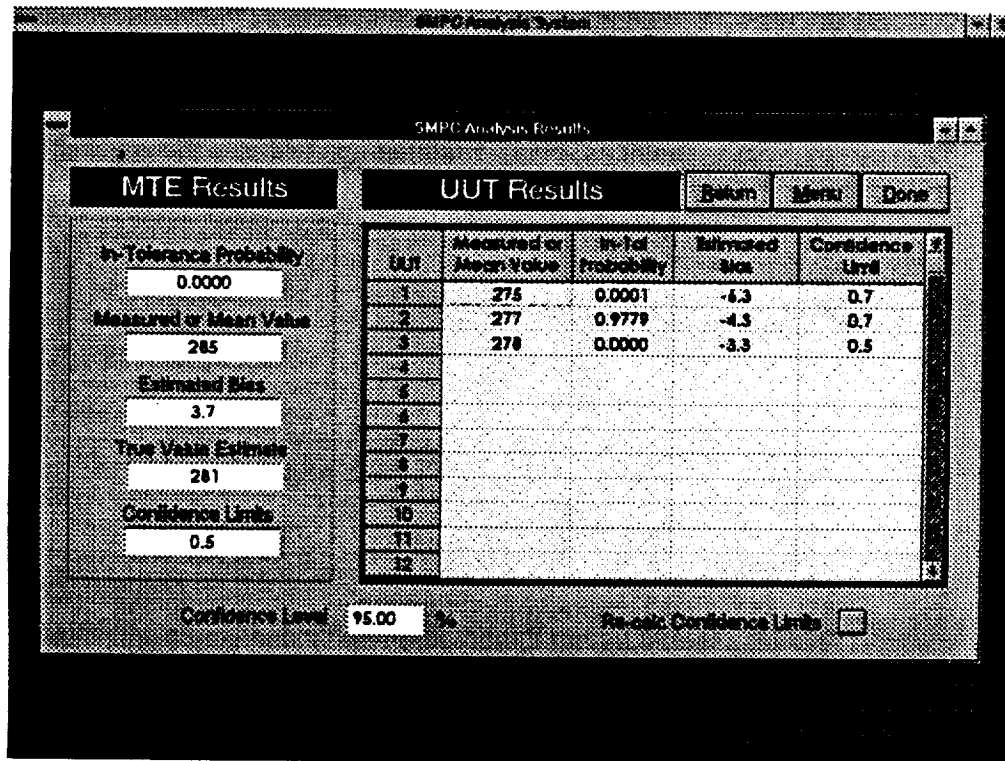
File Edit Report View Analysis Menu Help

Input Data:

UUT #	UUT Name	Mean or Mean Value	Tolerance Other	% In-Tol	Sample Size	Sample Std Deviation	UUT Error
0	Feelgood's Scale	285	1	95	1		
1	Howard's Scale	275	5	95	1		
2	Bob's Scale	277	5	95	1		
3	Wendell's Scale	278	1	95	1		
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## Using a Check Standard

- Now a 3rd UUT is brought into the picture that rivals the MTE for *a priori* accuracy. Let's examine the situation so far:
  - ➔ Both UUT1 and UUT2 more or less agree with one another.
  - ➔ Both UUTs disagree with the MTE.
  - ➔ The tolerances for the 3rd UUT are as tight as the MTE tolerances.
- This suggests an interesting possibility:
  - ➔ Use the 3rd UUT will as a check standard.



## SMPC Results

- In-tolerance probabilities:
  - MTE: 0.0000
  - UUT1: 0.0001
  - UUT2: 0.9779
  - UUT3: 0.0000
- Estimated biases:
  - MTE: + 3.7 lb
  - UUT1: - 6.3 lb
  - UUT2: - 4.3 lb
  - UUT3: - 3.3 lb
- Confidence limits:
  - MTE: Measured value - 3.7 lb  $\pm$  0.5 lb
  - UUT1: Measured value + 6.3 lb  $\pm$  0.7 lb
  - UUT2: Measured value + 4.3 lb  $\pm$  0.7 lb
  - UUT3: Measured value + 3.3 lb  $\pm$  0.5 lb

Both the MTE and the check standard are likely to be out-of-tolerance, given the measurement results and *a priori* assumptions. It may be worthwhile to go back and reexamine these assumptions.



SMPC Analysis System

SMPC Scratch Pad

File Edit View Options Window Help

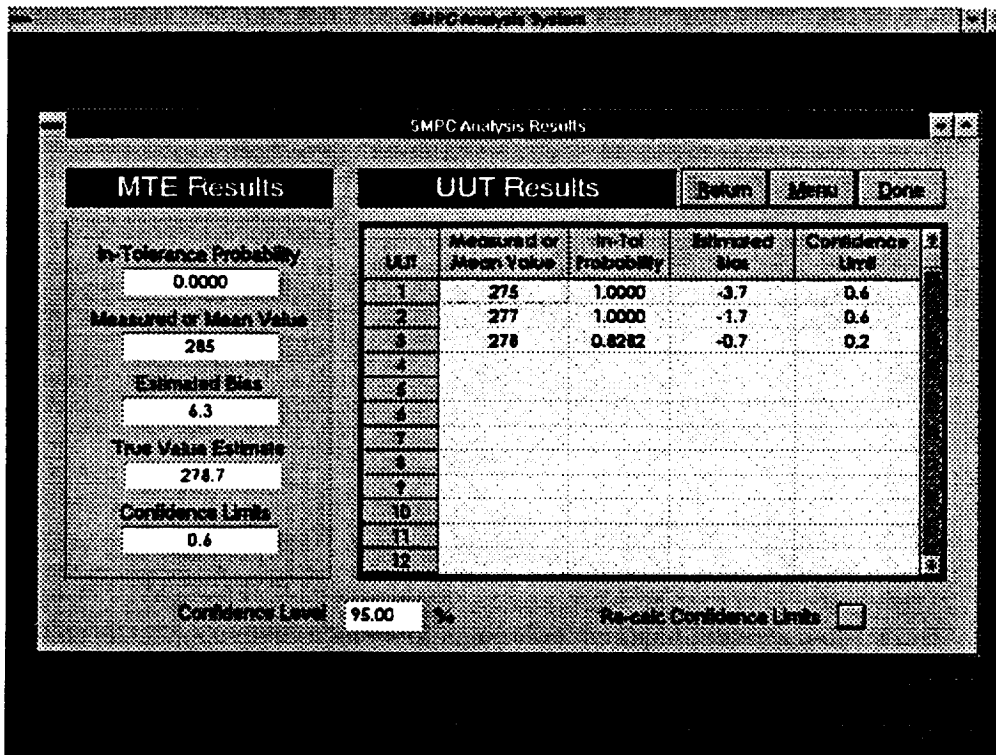
Input Data:

UUT #	UUT Name	Meas. or Mean Value	Tolerance Offset	% In-Tol	Sample Size	Sample Std Deviation	UUT Error
0	Feelgood's Scale	285	1	70	1		
1	Howard's Scale	275	5	70	1		
2	Bob's Scale	277	5	95	1		
3	Wendell's Scale	278	1	99.73	1		
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## Refining *a priori* Assumptions

At this point, we go back and re-think what we have to work with. Reviewing what we know about the MTE and the UUTs yields the following points:

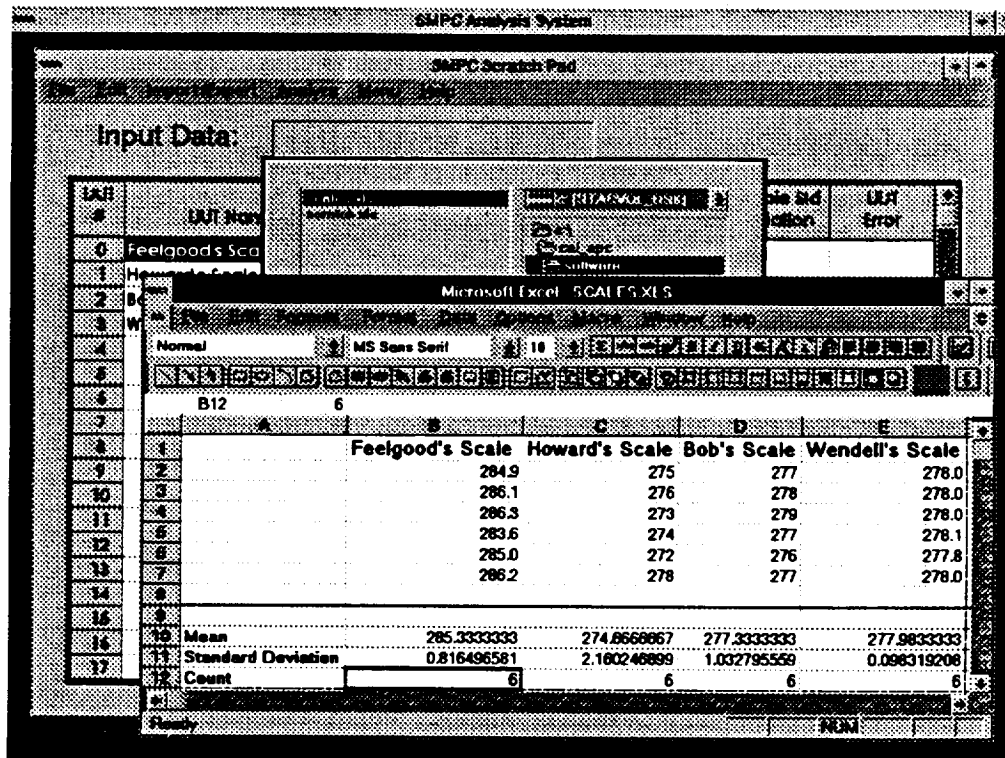
- ❑ The MTE resides in a physician's office. It was acquired about four years ago and has not been calibrated since. Its in-tolerance percentage is probably closer to 70% than 95%.
- ❑ UUT1 was purchased in 1992. It has been in service for a shorter time than the MTE but its inherent stability is not likely to be as good. We set its in-tolerance probability to equal that of the MTE, namely, 70%.
- ❑ UUT2 was recently purchased. Giving the manufacturer the benefit of the doubt, we leave its in-tolerance probability at 95%.
- ❑ UUT3 is owned by Wendell, a metrology engineer with a passion for accuracy. Wendell meticulously calibrates his scale with a set of reference weights directly traceable to NIST. We set his in-tolerance probability at 99.73% (3 sigma).



## Revised SMPC Results

Revising the *a priori* assumptions has produced some interesting consequences:

- ❑ UUT3 has indeed become "gold-plated."
- ❑ In-tolerance probabilities have been considerably revised.
- ❑ Estimated biases for UUTs 1 and 2 have diminished, while the MTE's estimated bias has increased.
- ❑ The MTE's confidence limits have expanded, while the confidence limits for the UUTs have contracted.
- ❑ Conclusions:
  - ➔ It looks like a recalibration of the MTE is definitely overdue.
  - ➔ UUT1 and UUT2 seem to be within spec with high probability.
  - ➔ UUT4, the gold-plated check standard, has an estimated in-tolerance probability that is much lower than the *a priori* value of 99.73%.
- ❑ Is there something that has been left out?



## Multiple Measurements - Data Sampling

- ☐ With single measurements, we are unable to estimate random uncertainty.
- ☐ We have *a priori* notions about the repeatability of the MTE and the UUTs, as embodied in their tolerance limits and other information, but these notions need experimental validation.
- ☐ Single measurements always leave open the question "is the measurement representative of the MTE/ UUT or is it just a statistical anomaly?"
- ☐ Accounting for random uncertainty or parameter repeatability helps refine confidence limit estimates.

SMPC Analysis System

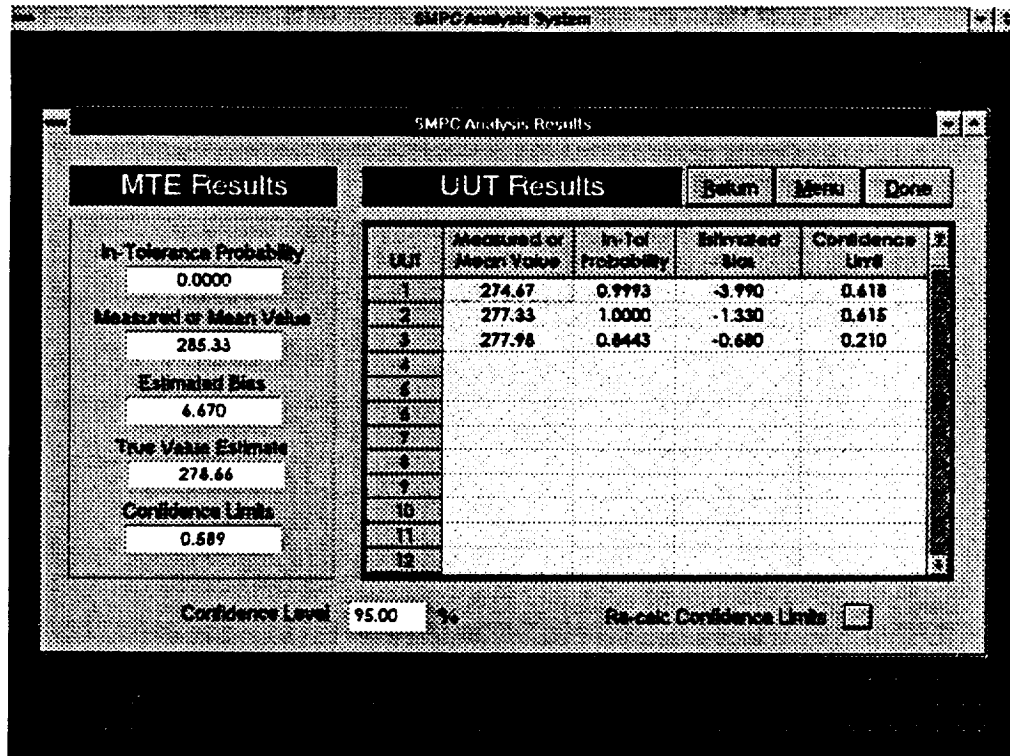
SMPC Scratch Pad

Input Data:

UUT #	UUT Name	Mean or Mean Value	Tolerance Offset	% In-Tol	Sample Size	Sample Std Deviation	UUT Error
0	Feelgood's Scale	285.33	1	70	6	0.8165	
1	Howard's Scale	274.67	5	70	6	2.1602	
2	Bob's Scale	277.33	5	95	6	1.0328	
3	Wendell's Scale	277.98	1	99.73	6	0.0983	
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## Multiple Measurements - Summarizing and Tabulating

- ❑ The sampled data show that the mean values are not far off from our previous single measurement values. This is reassuring.
- ❑ Sample standard deviations are in line with expectations for the MTE, UUT1 and UUT3.
- ❑ The sampled standard deviation for UUT2 is admirably low. This justifies our faith in Bob's scale and its manufacturer. (Remember, we assigned it a 95% in-tolerance level. If the sampled standard deviation had been large, we might have revised this figure downward.)



## Multiple Measurements - SMPC Results

- ❑ Taking measurement samples has had little effect on the SMPC results. (This will not always be the case. If any one or more of the single measured values had been anomalous, it could have skewed the results.)
- ❑ The high level of repeatability for UUT3 has moved its estimated in-tolerance probability closer to the *a priori* value of 0.9973, but not close enough to be believable.
- ❑ Given the circumstances, we place a great deal of confidence in the 0.9973 *a priori* in-tolerance probability for UUT3. Why is the SMPC estimate of 0.8443 so low? Is there another factor that we haven't accounted for?

SMPC Analysis System

SMPC Scratch Pad

Input Data:

LAB #	UUT Name	Mean or Mean Value	Tolerance Offset	% In Tol	Sample Size	Sample Std Deviation	UUT Error
0	Feelgood's Scale	285.33	1	70	6	0.8165	3
1	Howard's Scale	274.67	5	70	6	2.1602	3
2	Bob's Scale	277.33	5	95	6	1.0328	3
3	Wendell's Scale	277.98	1	99.73	6	0.0983	3
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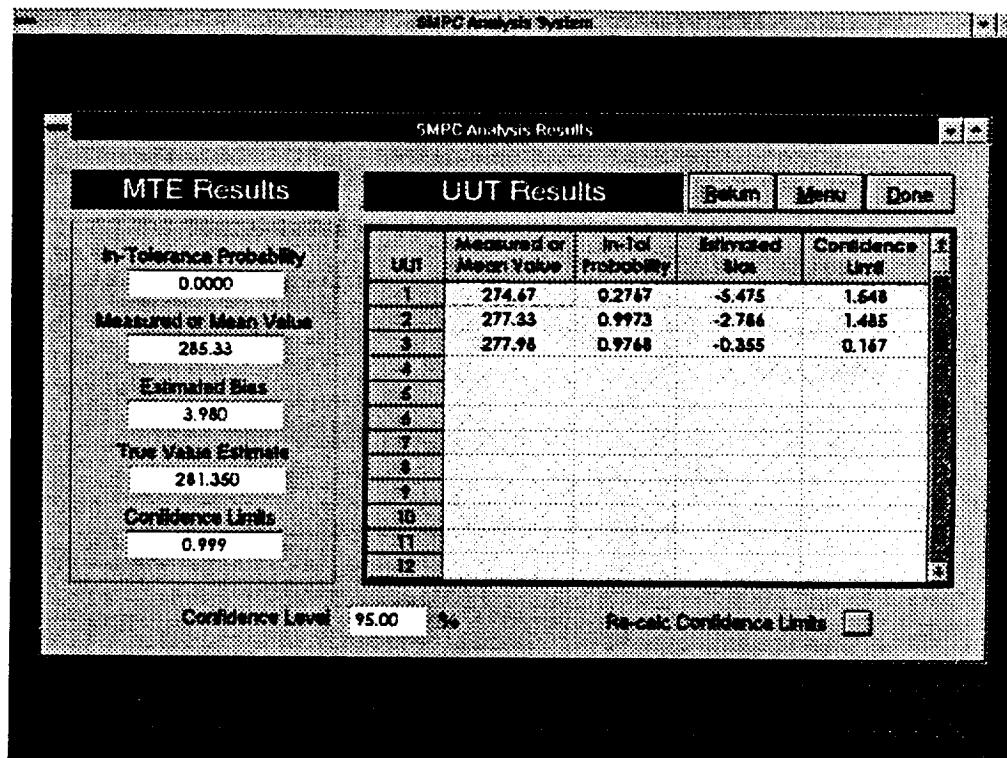
## Accounting for Measurand Variability

Up to this point, we have assumed that the quantity being measured was stable. We now examine this assumption. In the present example, the following applies:

- ☐ The quantity being measured (the transfer standard) is a person.
- ☐ No attempt was made to systematize the measurements with regard to duration over which the samples were taken (the sampling period) or to time of day, before or after lunch, etc.
- ☐ The transfer standard eats large meals three times per day (not counting a late night snack).

From this we conclude:

- ☐ 95% confidence limits of  $\pm 3$ lbs in UUT fluctuation uncertainty need to be included in the analysis.



## Accounting for Measurand Variability - SMPC Results

Including measurand fluctuations in the total uncertainty makes the results more believable:

- ❑ The nonconformity of the MTE is not as cut-and-dried as before. The MTE bias estimate has been reduced.
- ❑ Bias estimates for UUT1 and UUT2 have increased to values more in line with their specs and with their measurement samples.
- ❑ Probability estimates for UUT1 and UUT2 are more "reasonable."
- ❑ Confidence limits for all quantities are expanded, reflecting a level of uncertainty that we know is more sensible for the kind of measurements being taken.
- ❑ The gold-plated standard looks gold-plated again:
  - The bias estimate for UUT3 has been reduced.
  - The in-tolerance probability for UUT3 is nearly equal to its *a priori* value.

All in all, accounting for UUT variability has added a needed touch of realism to the analysis. As a consequence, the results are considerably more viable and reasonable.

## *Measurement Decision Risk Analysis*

### **SMPC Application**

- *SMPC uses UUT measurements to evaluate the MTE along with the UUT.*
- *External check standards can be used, but are not required.*
- *So, SMPC is useful for evaluating instruments on extended deployment:*
  - *Refine biases and confidence limits.*
  - *Evaluate in-tolerance probabilities.*

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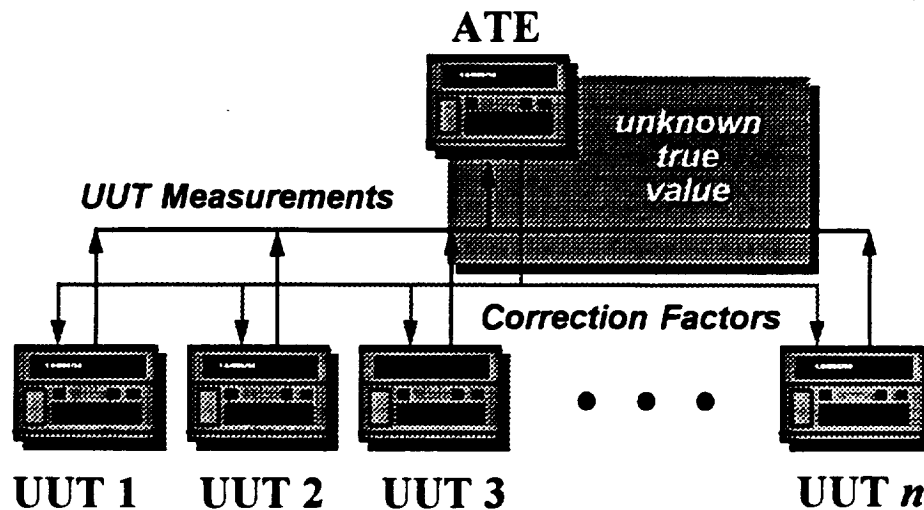
## **SMPC and Extended Deployment**

- **Uncertainty Growth Control**
  - Can supplement or, in some cases, replace periodic calibration of measuring systems.
  - Can supplement or, in some cases, replace periodic end item testing.
- **Self-Sufficiency**
  - Can be implemented without recourse external standards.
  - Can be automated for unattended applications.



## *Measurement Decision Risk Analysis*

### **Automated CONTROL without SMPC**

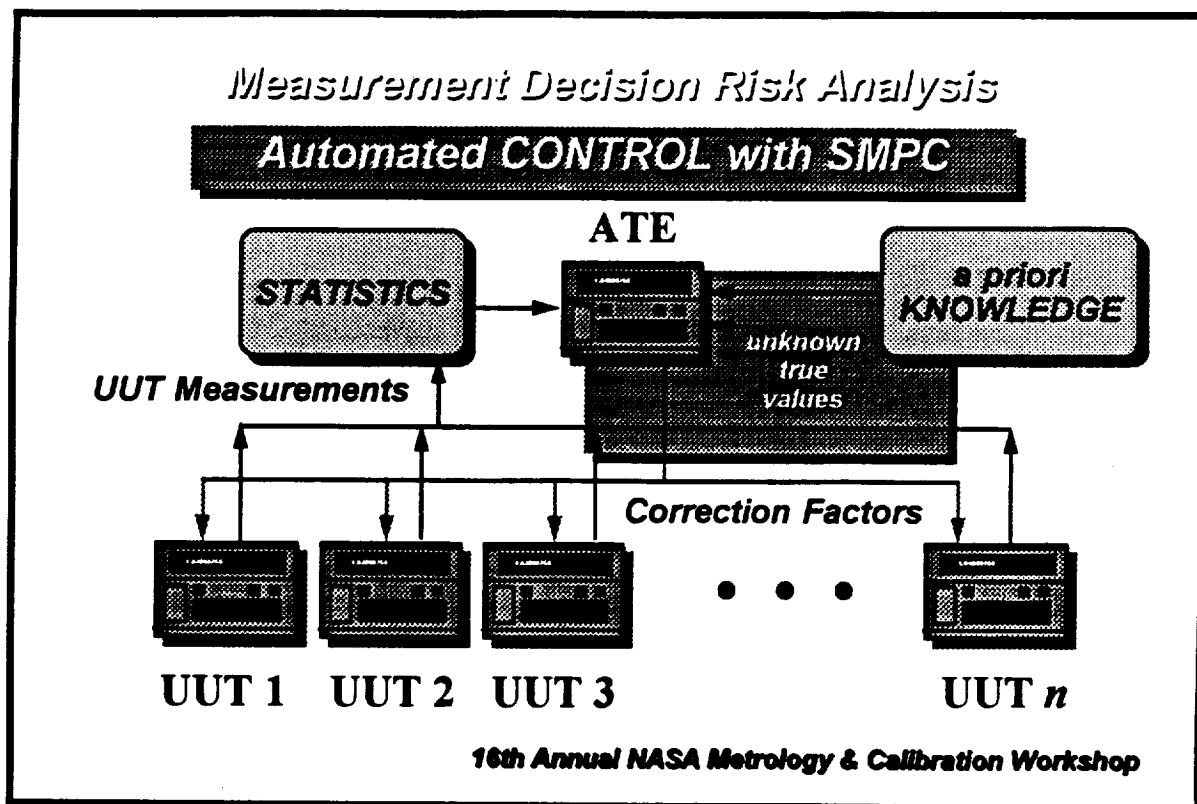


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## **The Customary ATE Configuration**

### **□ Correction Factors**

- Correction factors are computed as the differences between ATE and UUT attribute values.
- The ATE controller applies correction factors to the UUTs.



## SMPC ATE Implementation

### □ Correction Factors

- Correction factors are computed statistically as bias estimates.
- The ATE controller applies correction factors to the UUTs and to itself.
- The ATE controller computes in-tolerance probabilities for the UUTs and for itself.

### □ In-Tolerance Probabilities

- A low in-tolerance probability signals a possible need for external attribute verification.
- A low in-tolerance probability may result in a disconnect of the subject or ATE attribute from service.

### □ Process Diagnostics

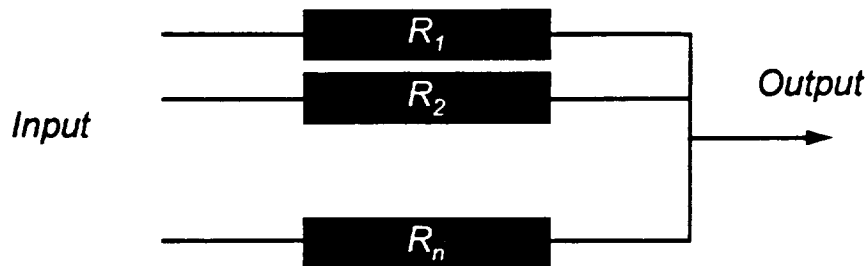
- Significant departures from *a priori* expectations may signify a measurement process deficiency.
- Excessively wide confidence limits may signify the same.

## *Measurement Decision Risk Analysis*

### **SMPC Design Concepts**

#### **1. Basic Reliability Axiom:**

*Parallel (redundant) design improves reliability*



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## **SMPC Design Implications**

### **□ Basic Reliability Axiom**

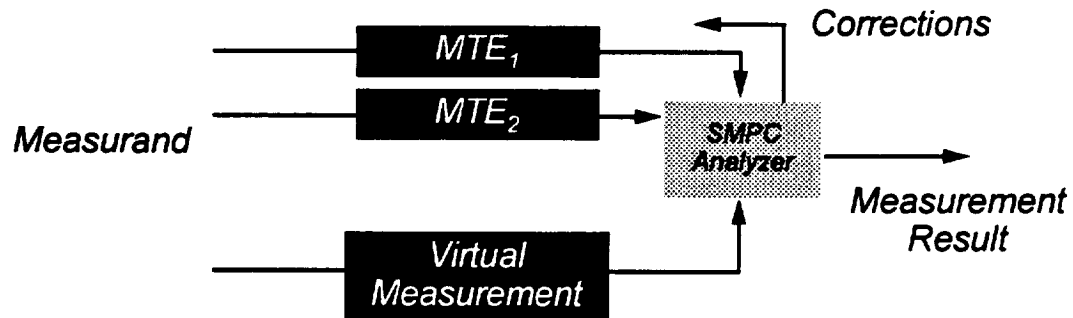
- Redundant design improves reliability
- The system works (an output is obtained) if one or more of the redundant components works.

## *Measurement Decision Risk Analysis*

### **SMPC Design Concepts**

#### **2. SMPC Counterpart:**

*Parallel (redundant) design improves measurement reliability*



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## **SMPC Reliability Counterpart**

### **□ Measurement Redundancy**

- ➔ The in-tolerance probability (measurement reliability) of the output result is arrived at through an analysis of the combined results of redundant measuring attributes.
- ➔ Redundant design improves measurement reliability.
- ➔ Virtual (projected) measurements can serve to "sanity check" the process.

## *Measurement Decision Risk Analysis*

### **SMPC Methodology**

#### **On the Drawing Board:**

##### **A general methodology**

*Extending the currently documented math to non-normally distributed measurements and attribute values.*

##### **Application software**

 *Modularized analysis applications distributed as dynamic link libraries.*

 *Goal-oriented algorithms for autonomous disconnect of measurement system outliers.*

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## **SMPC Technology**

### ☐ **Attribute Distributions**

- ➔ Current tools are tailored to normally distributed attributes.
- ➔ However, general methods have been formulated.

### ☐ **Methodology Implementation**

- ➔ A prototype "SMPC Analyzer," using current tools, has been developed as a Windows application.
- ➔ A general attribute distribution version is in the initial design stage.
- ➔ Algorithms are under development for making SMPC decisions in remote environments.



# NIST TOUR ITINERARY





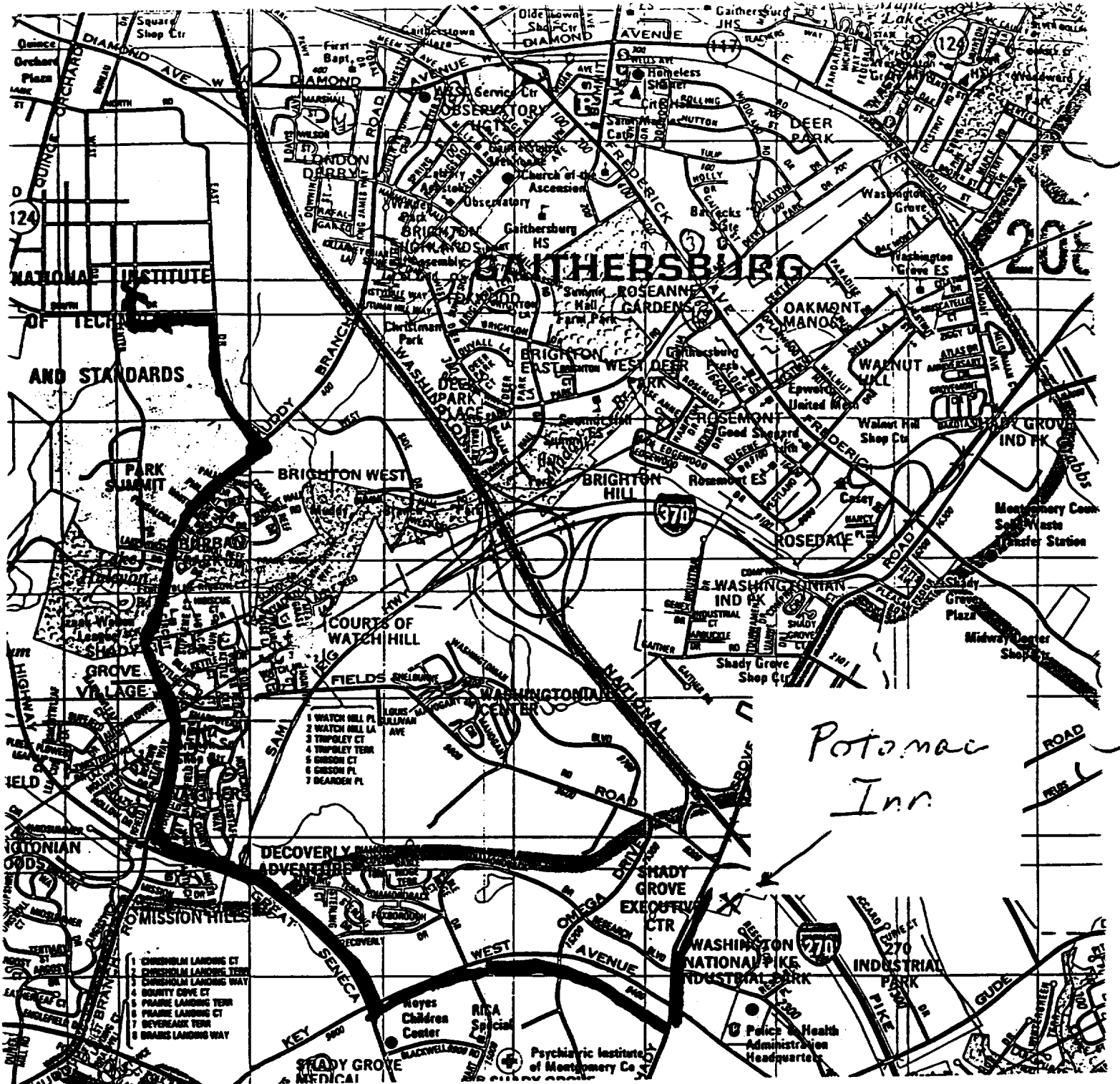
## **NASA Tour Instructions**

**NIST, Wednesday, April 21, 1993**

At 12:10 we will be breaking for lunch. Unfortunately, no bus service will be available, so we will have to car-pool to NIST. There will be one 15-passenger NIST van available. To make sure that the schedule can be kept, plan on leaving the hotel at 1:00 and follow the directions on the next two pages to arrive in front of the Physics Building (221) by 1:20 to meet the Tour Guides. You will be escorted by them to the tour stops roughly according to the schedule given on page 5 of this set of instructions. There will be shuttle transportation between Stop 1 and Stop 2 because of the distance. There will also be a van shuttling between the Physics Building (Stop 7) and Stop 1. The rest of the tour can be done totally in doors. Ten minutes have been allotted for movement between stops. In most cases, this will only take a few minutes, but the distances between stops 7 and 1, and stops 2 and 3 are such that at a brisk walk they each take about seven minutes to negotiate. Please try to leave the stops at the scheduled times and stick together.

Note that the "A" corridor of the general laboratory buildings (Metrology, Physics, and Technology) is on your right as you face the building from its parking lot, and the "B" corridor is on your left. If you become displaced, call Denise Prather on ext. 4221 for help.

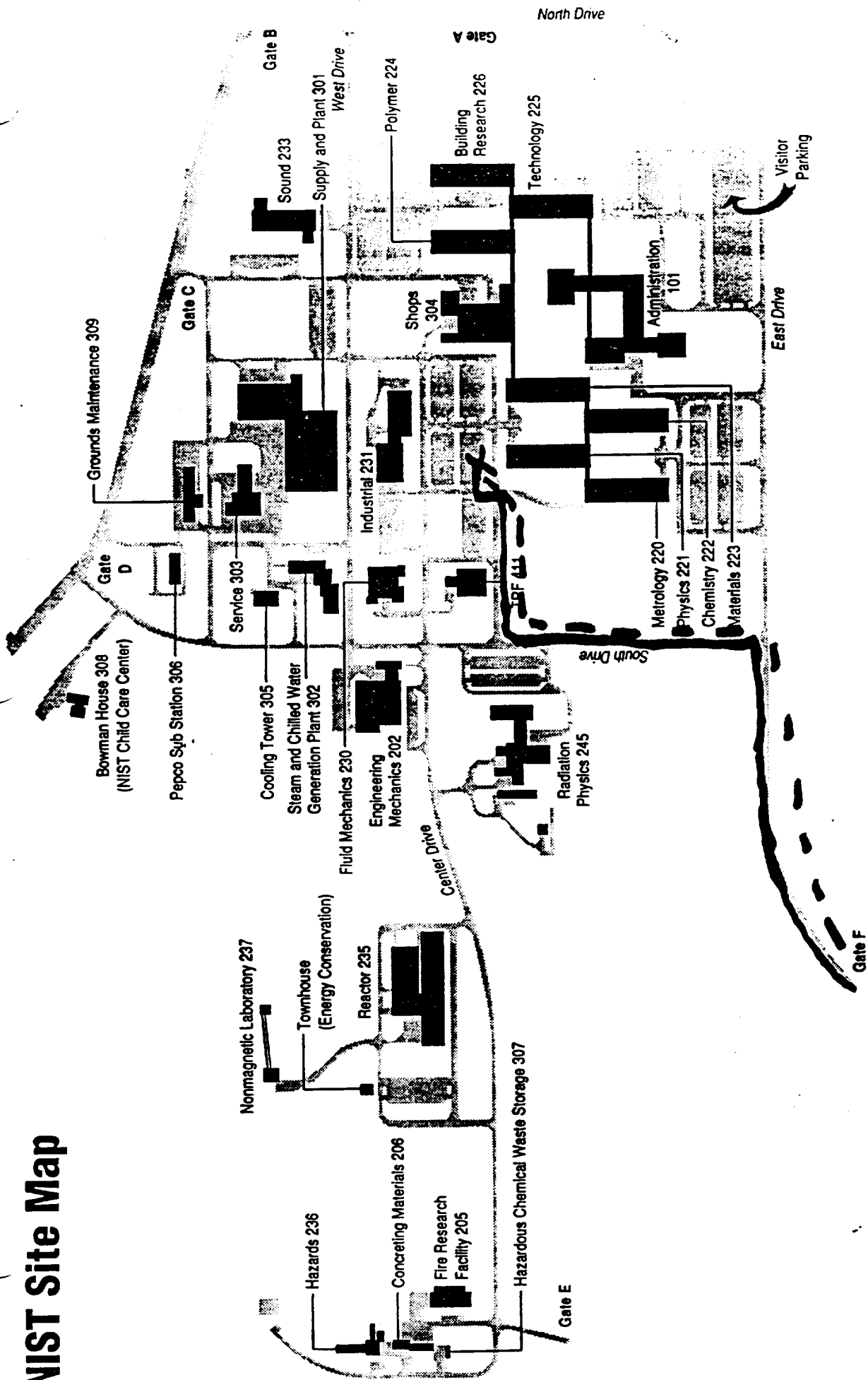
**In any emergency, call 2222.**



#### Directions to NIST:

Go out to Shady Grove Road. Turn left (west) and right on Key West Avenue (second light). Turn right on Great Seneca Highway (third major intersection). Turn right again on to Muddy Branch Road at the second intersection. Follow Muddy Branch turning left into the second entrance into NIST (Gate F). You will be on East Drive. Continue up the hill, past the ponds on your right, and turn left at the first place you can. You will be on South Road. Go along South Road and take the first right. You will then pass the TRF Building on your left and approach the Physics Building ahead on the right. Park where you can in front of the Physics or TRF buildings and assemble in front of the Physics Building to meet the Tour Guides.

# NIST Site Map



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**Group A starts at Stop 1 — Synchronized Ultraviolet Radiation Facility (SURF II)**  
Location: Radiation Physics Building, D05  
**Guide: Bob Dragoset or Bill Ott**

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**Group B starts at Stop 2 — Detector Characterization for GOES Weather Satellites**  
Location: Technology Building, Room A354  
**Guide: Barbara Belzer**

---

**Group C starts at Stop 3 — A BIVD Bridge to Support the NASA Zeno Experiment**  
Location: Metrology Building A153  
**Guide: Arnold Perrey**

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**Group D starts at Stop 4 — Hardness Indenter Calibrations and Surface Finish**  
Location: Metrology Building A 026  
**Guide: Brian Scace**

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**Group E starts at Stop 5 — Vacuum, Low-Pressure, and Leak-Rate Standards**  
Location: Metrology Building, Room A40  
**Guide: Dick Hyland**

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**Group F starts at Stop 6 — Low Background Infrared Calibration Facility**  
Location: Physics Building, Room A026  
**Guide: Jack Hsia**

---

**Group G starts at Stop 7 — Transient Pressure Standards**  
Location: Physics Building A012  
**Guide: Paul Boynton**

**TOUR Schedule**

<b>Times</b>	<b>1:30 - 1:50</b>	<b>2:00 - 2:20</b>	<b>2:30 - 2:50</b>	<b>3:00 - 3:20</b>	<b>3:30 - 3:50</b>	<b>4:00 - 4:20</b>	<b>4:30 - 4:50</b>
<b>Groups</b>							
<b>Group A</b>	Stop 1	Stop 2	Stop 3	Stop 4	Stop 5	Stop 6	Stop 7
<b>Group B</b>	Stop 2	Stop 3	Stop 4	Stop 5	Stop 6	Stop 7	Stop 1
<b>Group C</b>	Stop 3	Stop 4	Stop 5	Stop 6	Stop 7	Stop 1	Stop 2
<b>Group D</b>	Stop 4	Stop 5	Stop 6	Stop 7	Stop 1	Stop 2	Stop 3
<b>Group E</b>	Stop 5	Stop 6	Stop 7	Stop 1	Stop 2	Stop 3	Stop 4
<b>Group F</b>	Stop 6	Stop 7	Stop 1	Stop 2	Stop 3	Stop 4	Stop 5
<b>Group G</b>	Stop 7	Stop 1	Stop 2	Stop 3	Stop 4	Stop 5	Stop 6

---

**Stop 1 — Synchronized Ultraviolet Radiation Facility (SURF II)**

**Presenter:** Robert Madden

**Location:** Radiation Physics Building, D05 (take elevator to first sub basement - follow signs)

SURF II is an electron storage ring, circulating electrons at an electron energy of 300 MeV. It is used as a source of continuum radiation at wavelengths from the visible spectral region down to 4 nm in the soft X-ray region. It has a peak output in the 10 - 15 nm region. The "light" from SURF II is used to carry out a variety of experiments in atomic/molecular physics and solid-state/surface physics, involving applications in atmospheric and ionospheric studies, high  $T_c$  superconductivity, catalysis, and multi-layer optical devices. The radiation from SURF II is also very accurately calculable, and therefore SURF II is used to radiometrically calibrate space experiments in the attached NASA Spectrometer Calibration Facility.

---

**Stop 2 — Detector Characterization for GOES Weather Satellites**

**Presenters:** D. G. Seiler and J. R. Lowney

**Location:** Technology Building, Room A354

NIST has aided NOAA in evaluating its GOES weather satellites by performing a number of measurements on the HgCdTe infrared detectors used in the satellites. Some of the detectors used in early satellite performance tests showed loss of detectivity over time. NIST has contributed to the resolution of this problem by: 1.) investigating the packaging and bonding procedures used in manufacturing these detectors; 2.) using high-field magneto-transport measurements and theoretical modelling to characterize the accumulation layers that result from surface passivation; and 3.) developing test structure methodology for quality control during processing.

---

**Stop 3 — A BIVD Bridge to Support the NASA Zeno Experiment**

**Presenter:** Svetlana Avramov

**Location:** Metrology Building A153

Zeno is a microgravity fluid dynamics experiment scheduled to fly on the space shuttle in 1994. For the past three years, NIST staff have been working with Bob Gammon and Svetlana Avramov at the University of Maryland to support the inductive voltage dividers used in this experiment. A binary inductive divider (BIVD) bridge was developed at NIST and used to test the differential linearity of the IVDs used in the Zeno engineering and flight models. The bridge, the results of the tests, and a method of decomposing linearity errors will be described.

---

**Stop 4 — Hardness Indenter Calibrations and Surface Finish**

**Presenter:** Fred Rudder and Tom McWaid

**Location:** Metrology Building A 026

The measurement of microform is taking place in this laboratory. In particular, we are developing a calibration system for measuring the radius, flank angle, and other parameters of hardness indenters. The quality of these indenters is crucial to the accurate measurement of the hardness of materials. We are also showing a tunnelling microscope for the measurement of surface finish to the sub-nanometer level.

---

**Stop 5 — Vacuum, Low-Pressure, and Leak-Rate Standards**

**Presenter:** Charles Tilford

**Location:** Metrology Building, Room A40

Until recently there has been a gap between NIST high-vacuum and low-pressure standards. This gap has been closed with the completion of the Transition Range standard and further improvements are underway with the development of an ultrasonic oil manometer. These standards will be an important part of a new NASA-sponsored program to develop improved low-pressure transfer standards. There has also been considerable progress in the development of leak standards and calibration facilities, including the development of a leak comparison system of the type that has been delivered to the Kennedy Space Flight Center. These standards and systems can be seen in the Vacuum laboratory, which also houses the NIST high vacuum and ultra high vacuum primary standards and calibration facilities.

---

**Stop 6 — Low Background Infrared Calibration Facility**

**Presenters:** Raju Datla and Steve Lorentz

**Location:** Physics Building, Room A026

Infrared sensors are used throughout NASA and DoD for a wide range of applications including Earth resource monitoring and ballistic missile defense. These sensors must be calibrated to ensure measurement accuracy and manufacturer compliance with specifications. The Low Background Infrared Calibration Facility (LBIR) was developed to provide a reference calibration and furnish leadership for research and development in infrared measurements. A companion facility has been developed to provide accurate measurement services required by industrial customers in, for example, the photographic and lighting industries.

---

**Stop 7 — Transient Pressure Standards**

**Presenter: Vern E. Bean**

**Location: Physics Building A012**

NIST is developing the capability to certify the accuracy of transducers used for the measurement of transient pressure. This new, national standard will be unique in that it is based on a molecular-level primary standard for transient pressure. This standard will be realized in a gas driven shock tube which will serve as the reference for the calibration of transducers. The laboratory realizations of both the primary and reference standard will be discussed at this tour stop.

---



# MAP REPORTS



**Jet Propulsion Laboratory**  
California Institute of Technology  
Pasadena, California

**Acceleration MAP Progress Report**

**April 22, 1993**

**Prepared by**

**Miguel Cerezo**

**Jet Propulsion Laboratory  
Instrumentation Section**

**Sixteenth NASA Metrology and Calibration Workshop**

**Rockville, Maryland**

## **ABSTRACT**

In 1989, the NASA Metrology Working Group implemented an Acceleration Measurement Assurance Program (AMAP) in order to allow each center to assess the quality of accelerometer calibrations being performed by their respective calibration laboratories. This report presents the data which has been submitted to the program during the time period between May 1992 and March 1993. Included is a detailed compilation of the transfer standard frequency response measurements and an interlaboratory comparison analysis of the 100 Hz pick-up sensitivity measurements which have been performed by the participants. Additionally, possible sources of bias measurement errors, which have surfaced in some of the AMAP data, are discussed.

Expansion of the AMAP includes the capabilities to perform Low Frequency Low Amplitude and one G and lower DC calibrations. Future expansion of the AMAP may include microgravity, transportation shock, and pyro shock calibrations.

## **INTRODUCTION**

The Jet Propulsion Laboratory has been assigned the responsibility for developing and conducting an acceleration measurement assurance program (AMAP) and serves as the pivot laboratory for the project. The purpose of the AMAP is to provide a dependable and cost effective method for participating NASA installations to assess the quality of measurements made for accelerometer calibration. The following are just a few of the benefits that result from participation in this program:

- 1) Provides NIST traceability.
- 2) The possible discovery of bias and precision errors which may have been previously undetected.
- 3) Allows participating centers to quantitatively assess the measurement errors associated with their accelerometer calibration systems and procedures.
- 4) Allows NASA to gain an understanding on the quality of accelerometer calibrations being performed on an agency-wide basis.

The method of implementation for this MAP is the "hub of the wheel" concept. In this way, two transfer standards are paired and shipped from JPL to the participating facilities and back to JPL after the test. This method provides various benefits such as facilitation of the formulation of Youden diagrams, multiple test runs for data confirmation, periodic reinspection of the equipment

to ensure no damage had occurred in transit, and also the ability to accumulate data in a progressive fashion throughout the MAP cycle.

## PARTICIPANTS

The following is the list of current AMAP participants:

Dryden Flight Research Facility  
Goddard Space Flight Center  
Jet Propulsion Laboratory  
Johnson Space Center  
Kennedy Space Center  
Langley Research Center  
Lewis Research Center  
Marshall Space Flight Center  
Stennis Space Center

## AMAP OVERVIEW

Each center was shipped two Endevco model 2270M8 transfer standard accelerometers along with instructions to calibrate them as though they were test units. Special mounting instructions were also provided, but no information regarding the accelerometers' sensitivity or frequency response was given other than that which can be obtained from the manufacturer's specifications.

The AMAP concentrates on two specific accelerometer calibration measurements. These are:

- 1) The single point sensitivity in pC/g, to four significant figures, using a frequency of 100 Hz at an acceleration level between 2 and 10 g.
- 2) The frequency response curve. Participant data was presented to JPL as a plot or table of percent deviation or sensitivity versus frequency. Any range between 5 Hz to 10 KHz is acceptable.

As part of the AMAP, the four transfer standard accelerometers were sent to the National Institute of Standards and Technology (NIST) for calibration. The estimated uncertainty of the NIST sensitivity calibrations is  $\pm 1\%$  of reading at 100 Hz. This uncertainty is based on interferometric measurements and is considered to be an absolute calibration. The NIST frequency response measurements have an estimated uncertainty of  $\pm 2\%$  from 10 Hz to 50 Hz,  $\pm 1\%$  from 100 Hz to 2500 Hz, and  $\pm 2\%$  from 2500 Hz to 10 KHz.

The NIST calibrations are used as guide-lines for the estimated uncertainties of the transfer standards and are used for comparison purposes only. Ultimately, it

is the responsibility of each NASA participant to determine whether or not their particular accelerometer calibration requirements are being satisfied. These comparisons are merely a tool which may aid them in this process.

## FREQUENCY RESPONSE MEASUREMENTS

An analysis of the frequency response curves submitted by each of the nine participating centers is presented in figures 1 through 9. These plots show the deviation (in percent) between the participants' frequency response measurements and those performed by NIST. The bold lines indicate the estimated limits of uncertainty of the AMAP standard calibration which is based on the quoted NIST uncertainties. The serial number corresponding to the transfer standard accelerometer which was calibrated is indicated to the right of the graph.

### DFRF

The Dryden Flight Research Facility has participated in the AMAP by calibrating all four of the transfer standard accelerometers between the frequency range of 30 Hz to 5 KHz. The four curves are repeatable to within approximately 0.5% and are within the estimated uncertainty limits of the AMAP transfer standards throughout most of the calibration frequency range. (Figure 1). A bias of approximately 0.8%, with respect to NIST, is exhibited in the plots and the curves begin to drop off at approximately 3 KHz.

### GSFC

Due to time constraints, the Goddard Space Flight Center was only able to calibrate two transfer standard accelerometers as part of their participation in the AMAP. These two calibrations spanned the frequency range of 10 Hz to 1700 Hz and exhibited a flat response. Both calibrations submitted by GSFC show an offset of approximately -0.7% from the NIST calibrations. However, the frequency response curves are within the NIST uncertainty limit throughout the frequency range (Figure 2). Furthermore, the level of repeatability between the two calibrations indicates that precision errors and errors associated with drift in calibration, of the electrical components which make up the calibration system, are minimal.

### JPL

The Jet Propulsion Laboratory has participated in the AMAP by calibrating all four of the transfer standard accelerometers between the frequency range of 10 Hz to 4 KHz. These four calibrations are approximately 0.4% lower in sensitivity than the NIST values for the accelerometers at 100 Hz (Figure 3). At 2000 Hz, the JPL response curve shows a sharp drop as compared to the NIST high frequency sensitivity measurements. Some factors which might cause deviations from a straight line at high frequencies are the use of an isolating

stud with the sensor, burrs on the armature head of the shaker, or problems associated with high frequency filtering of the calibration system.

### JSC

Johnson Space Center participated in the AMAP by calibrating all four transfer standard accelerometers. The frequency response data is within the NIST estimated uncertainty limits between the frequency ranges of 30 Hz-50 Hz and 2.5 kHz-10 kHz but is not within the NIST uncertainty between the range of 50 Hz-2.5 kHz (Figure 4). Analysis of the AMAP data indicates that a bias (with respect to NIST) on the order of + 1.5% is present in the JSC accelerometer calibration system. In reviewing the 100 Hz pickup sensitivity data, we find that the JSC measured value for accelerometer JA71 is approximately 1.4% higher than that which was measured at NIST. For accelerometer JA62, the deviation is approximately +1.6%. It is possible that this bias error has been passed on to the JSC accelerometer calibration system by a transfer standard accelerometer which was used to calibrate the JSC working standard. In order to rectify this bias problem the AMAP transfer standards, with the NIST calibration data, may be used to determine the 100 Hz sensitivity value of the JSC working standard accelerometer. Arrangements can be made so that the AMAP transfer standard accelerometers may be returned to JSC for these measurements if it is desired.

At 3000 Hz, the JSC response curve shows a sharp drop as compared to the NIST high frequency sensitivity measurements. Some factors which might cause deviations from a straight line at high frequencies are the use of an isolating stud with the sensor, burrs on the armature head of the shaker, or problems associated with high frequency filtering of the calibration system.

### KSC

As part of their participation in the AMAP, Kennedy Space Center calibrated all four transfer standard accelerometers. The KSC frequency response curves are within the transfer standard uncertainty limits except for the 2500 Hz point on accelerometer JA62 (Figure 5). Beyond 6 KHz, the repeatability of the curves tends to decrease and approaches a dispersion on the order of  $\pm 1.5\%$  at 8 KHz. A thin coating of light lubricant or acoustic couplant at the base of the transfer standard accelerometer may help to increase the precision of the KSC measurements at the higher calibration frequencies.

### LaRC

Langley Research Center calibrated four transfer standard accelerometers as part of their participation in the AMAP. Two calibrations span the range from 10 Hz to 10 KHz and two additional calibrations were performed in the frequency range of 30 Hz to 10 KHz. The four curves are repeatable to within 0.5% and are all well within the estimated uncertainty limits of the AMAP transfer standards (Figure 6). The calibration curves show a slight increase in response at 2000 Hz where the accelerometer sensitivity rises as it approaches

resonance. This could be due to a combination of the AMAP and working standard accelerometer responses on the calibrator and is considered normal.

### LeRC

As part of their participation in the AMAP, Lewis Research Center calibrated all four transfer standard accelerometers. Below 5 KHz, the LeRC frequency response curves are within the transfer standard uncertainty limits except for the 50 Hz point on accelerometer JA71 (Figure 7). Beyond 5 KHz, the repeatability of the curves tends to decrease and approaches a dispersion on the order of  $\pm 5\%$  at 7 KHz. This large deviation at high frequencies may be caused by a system resonance lower than the 40 KHz accelerometer resonant frequency. A low system resonance could be caused by defective mounting studs or armature heads which are made of soft metals such as aluminum or a shaker armature suspension which has lost some of its rigidity. Also, the wrong type of electrical filtering on the output of the working standard accelerometer could cause this effect.

### MSFC

Marshall Space Flight Center calibrated all four transfer standard accelerometers during this phase of the AMAP. The MSFC frequency response curves are within the transfer standard uncertainty limits except for the 50 Hz point on accelerometer JA71 (Figure 8).

### SSC

Stennis Space Center participated in the AMAP by calibrating two transfer standard accelerometers. Further participation by SSC was delayed due to the fact that new personnel are being trained to perform accelerometer calibrations. The frequency response data submitted by SSC is within the NIST estimated uncertainty limits between the frequency range of 10 Hz - 50 Hz but is not within the NIST uncertainty limits between the range of 50 Hz - 1000 Hz (Figure 9). Analysis of the AMAP data indicates that a bias (with respect to NIST) on the order of + 1.5% is present in the SSC accelerometer calibration system. In reviewing the 100 Hz pickup sensitivity data, we find that the SSC measured value for accelerometer JA78 is approximately 1.3% higher than that which was measured at NIST. For accelerometer JM63, the deviation is approximately +1.6%. It is possible that this bias error has been passed on to the SSC accelerometer calibration system by a transfer standard accelerometer which was used to calibrate the SSC working standard. In order to rectify this bias problem the AMAP transfer standards, with the NIST calibration data, may be used to determine the 100 Hz sensitivity value of the SSC working standard accelerometer. Arrangements can be made so that the AMAP transfer standard accelerometers may be returned to SSC for these measurements if and when it is desired.



## YOUDEN DIAGRAMS

A Youden diagram is a statistical tool which is widely used to graphically represent and analyze interlaboratory comparison data (Youden, W. J., 1969). Essentially, Youden diagrams are formed by setting up a scale on the X axis of a Cartesian plot which will cover the range of measured values for one transfer standard and repeating the process for another transfer standard on the Y axis. The results reported by each participating center, for both transfer standards, are used to plot a point on the graph. There will be as many points as there are reporting laboratories.

Analysis of the interlaboratory comparison data is achieved by adding four key elements to the Youden diagram (Conroy, B. F., 1991). First, the median of the measured values submitted by each participant, for both transfer standards, is calculated and a line is drawn through the median value perpendicular to the corresponding axis. The next element is a 45 degree tangent line which is drawn through the intersection of the median lines. An uncertainty circle, of radius three times the standard deviation of the measured values used in calculating the median, is also added to the Youden diagram. For comparison purposes and to assess the accuracy of the measurements submitted by each of the participating centers, NIST data is included on the graph. The NIST point is shown as an asterisk and the error bars associated with the point is the NIST estimated uncertainty and is independent of the group mean.

Based on the information given by the Youden diagrams developed from the data submitted for evaluation as part of the AMAP, it is possible to quantitatively assess the errors associated with the accelerometer calibration systems and procedures utilized at each of the participating NASA facilities. These Youden diagrams, which are based on the 100 Hz accelerometer output sensitivities of the AMAP transfer standards, can be found in figures 10 and 11. Since not all of the centers were able to participate in each of the four rounds of the AMAP, some centers are more represented, in the plots, than others.

## AMAP ERROR ANALYSIS

The two components which make up a calibration laboratory's total measurement error are known as precision errors and bias errors. Precision errors result from the inability of a given laboratory to make precise, repeatable measurements and are caused by factors such as calibration drift in the equipment used to perform the measurements, stability of the environment, faulty cables and standards, and non repeating operator errors. In reviewing the Youden diagrams, laboratories whose measurements are primarily influenced by precision errors will have data points which fall into the upper left and lower right quadrants and will be far from the 45 degree tangent line. On the other hand, laboratories whose data point does fall along the 45 degree tangent line have performed repeatable measurements which are primarily influenced by bias errors caused by inherent biases in the standards and procedures

employed. In either case, the magnitude of the total measurement error can be ascertained from the distance between a laboratory's data point and the group mean.

#### JA62 vs. JA71

The Youden diagram which plots the 100 Hz accelerometer output sensitivity measurements performed on transfer standard JA62 versus transfer standard JA71 can be found in figure 10. Seven AMAP participants are represented in this diagram. Additionally, the NIST data point is plotted for comparison purposes. All seven of the points representing the AMAP participants fall within close proximity of the 45 degree tangent line. This fact would indicate that the participants are performing repeatable 100 Hz accelerometer sensitivity measurements. Furthermore, five of the seven data points lie within the NIST estimated uncertainty and no points were outside of the  $3\sigma$  uncertainty circle.

#### JA78 vs. JM63

Figure 11 shows the Youden diagram which was formed by plotting the JA78 measured sensitivity values versus those submitted for transfer standard JM63. Nine AMAP participants are represented on this graph. Once again, all of the points representing the AMAP participants fall within close proximity of the 45 degree tangent line thus providing evidence that the precision component of the participant's measurement errors are small. Thus, bias errors account for the majority of the deviation between the NIST measurements and the participant's measurements. The magnitude of the bias error for each particular participant is indicated by the distance between the NIST data point and the participants data points. Seven of the nine participants represented on this diagram fall within the estimated NIST uncertainty limits and only one lies outside of the  $3\sigma$  uncertainty circle.

#### Youden Diagram Summary

Table 1 summarizes the information derived from the two Youden diagrams developed from the AMAP data.

Youden Diagram	Centers With Predominantly Precision Errors	Centers With Predominantly Bias Errors	Number of Points Outside of NIST Estimated Uncertainty Limits	Number of Points Outside of $3\sigma$ Uncertainty Circle
JA62 vs. JA71	None	All	2	0
JA78 vs. JM63	None	All	2	1

Table 1. Youden Diagram Summary

## FUTURE PLANS

At the present time, the AMAP covers only a limited region of the accelerometer calibration spectrum that JPL and NASA intends to pursue. Funding for these future efforts will depend on fiscal support from NASA. The regions for future expansion are listed below:

- 1) Low Frequency Large Amplitude
- 2) Transportation and Pyrotechnic Shock
- 3) Micro G (0.01 G to 10  $\mu$ G)

### Low Frequency Large Amplitude (LFLA) Calibration

Installation, integration, testing and verification of the LFLA calibration system is now complete. The funds allocated for this effort purchased only a portion of the fully automated and full range calibrator. This procurement is referred to as the "starter" LFLA calibrator.

Specifications call for a calibrator to cover the range from 0.1 to 200 Hz. The starter system will cover the range from 1 Hz to 200 Hz. Work is currently underway to extend the LFLA calibration system's frequency range down to 0.1 Hz and to enhance the system's flexibility. It uses a long stroke (6 in. peak to peak) shaker. The support equipment has some automatic and some manual features. All equipment purchased for the starter LFLA calibrator can be utilized for the fully automatic LFLA and 5 Hz to 50 KHz calibrator. In addition, the shock calibrator will also use much of this same equipment. This procurement strategy has been adopted to minimize total costs over the procurement process and equipment life cycle.

In addition to the 0.1 to 200 Hz frequency range, DC calibrations will be performed using the earth's gravitational field. This will be accomplished with the use of a rotary tilt table aligned parallel to the earth's field for 1 G calibrations and tilted at various angles to the earth's field for lower full scale calibrations.

AMAP participants will be contacted to determine their requirements for participation in the LFLA calibration MAP. In addition, a calibration service will be made available to all users of accelerometers within the amplitude and frequency range of the LFLA calibration system.

### Transportation and Pyrotechnic Calibration

A request was submitted to the NASA Metrology Working Group for support to implement a shock calibration system in FY91 and FY92. The funds were not made available and the request will be resubmitted in FY93. The system will consist of two calibrators. Transportation shock will utilize a drop tester, and pyrotechnic shock will use both the drop tester and a Hopkinson Bar calibrator. The system configuration has not been fully determined at this time, but will use much of the equipment which was purchased for the LFLA calibrator.

### Microgravity Calibration

Space Station Freedom, the International Microgravity Laboratory, and the Shuttle program will require greatly expanded calibration capabilities to support anticipated microgravity experiments. The sensors must be evaluated and unique calibration methods implemented. If in-flight calibrations are required, innovative solutions will be necessary to solve the problems. Of particular concern is the problem of eliminating the necessity of a stable reference for the calibrator. JPL intends, with the participation of LeRC and MSFC, to seek FY93 funds to pursue the research to provide solutions and purchase equipment to provide this service.

### CONCLUSION

Through this phase of the NASA Metrology Working Group's Acceleration Measurement Assurance Program the nine participants have submitted thirty two calibrations which were performed on the four transfer standard accelerometers used in the MAP. With respect to the frequency response calibrations, nineteen of the thirty two submitted calibrations were completely within the estimated uncertainty limits of the AMAP transfer standard accelerometers.

Youden diagrams were used to graphically display the measured 100 Hz accelerometer sensitivity data. Based on the information contained in these plots, it was possible to assess the measurement errors in each of the nine participating NASA centers' accelerometer calibration systems and procedures. The total measurement errors can be ascertained from the distance between a participant's data point and the group mean. The significance of these measurement uncertainties is left to each center to evaluate. Any center whose calibrations did not fall within the NIST estimated uncertainty limits and the  $3\sigma$  uncertainty circle should review this data and determine if their accelerometer calibration capabilities satisfy their center's requirements.

The Youden analysis of this data set demonstrates a significant improvement over last year's data in the reduction of the precision errors inherent in the AMAP participant's measurements. In a previous report (Cerezo, M., 1992) it was shown that three of the nine centers performed measurements which were predominantly influenced by precision (or random) errors. This year, there were none.

A wide variety of accelerometer calibration data has been submitted to JPL for analysis as part of the AMAP. Through evaluation of this data, several possible sources of bias errors have been uncovered. These include errors associated with the polarity of the input signals to the X-Y plotters on calibrators, calibration drift in the electrical components, and faulty equipment such as cables, mounting studs and working standards.

Currently, the LFLA portion of the AMAP is operational. Surveys will be distributed to the AMAP participants in order to determine the requirements of centers which plan to participate in this phase of the program. Also as part of the LFLA portion of the AMAP, a low frequency, low amplitude accelerometer calibration service will be made available to all NASA centers. Additional expansion of the AMAP may include microgravity calibrations, transportation shock calibrations, and pyro shock calibrations and are dependent on funding.

#### REFERENCES

- Youden, W. J., "Graphical Diagnosis of Interlaboratory Test Results", Precision Measurement and Calibration: Statistical Concepts and Procedures, NBS Special Publication 300; vol. 1, 1969
- Conroy, B. F., "A Round-Robin Measurement Assurance Program for Thread Gage and Pitch Diameter Measurements", Paper presented at the National Conference of Standards Laboratories Workshop and Symposium, Albuquerque, NM, 1991
- Cerezo, M. "Acceleration MAP Progress Report", Proceedings of the Fifteenth NASA Metrology and Calibration Workshop, Johnson Space Center, Houston, TX, 1992

# NASA Metrology Working Group Acceleration Measurement Assurance Program

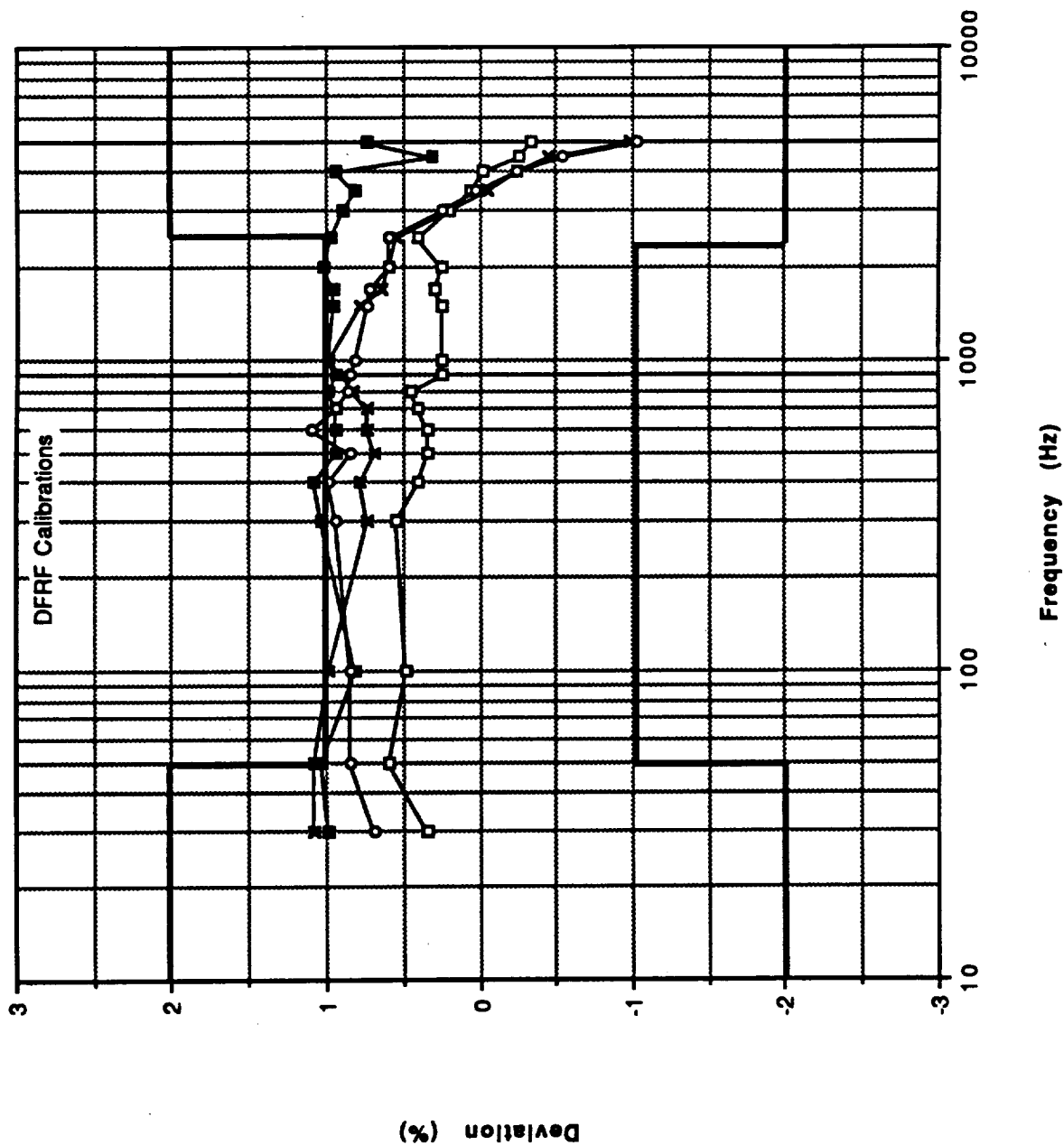


Figure 1

# NASA Metrology Working Group Acceleration Measurement Assurance Program

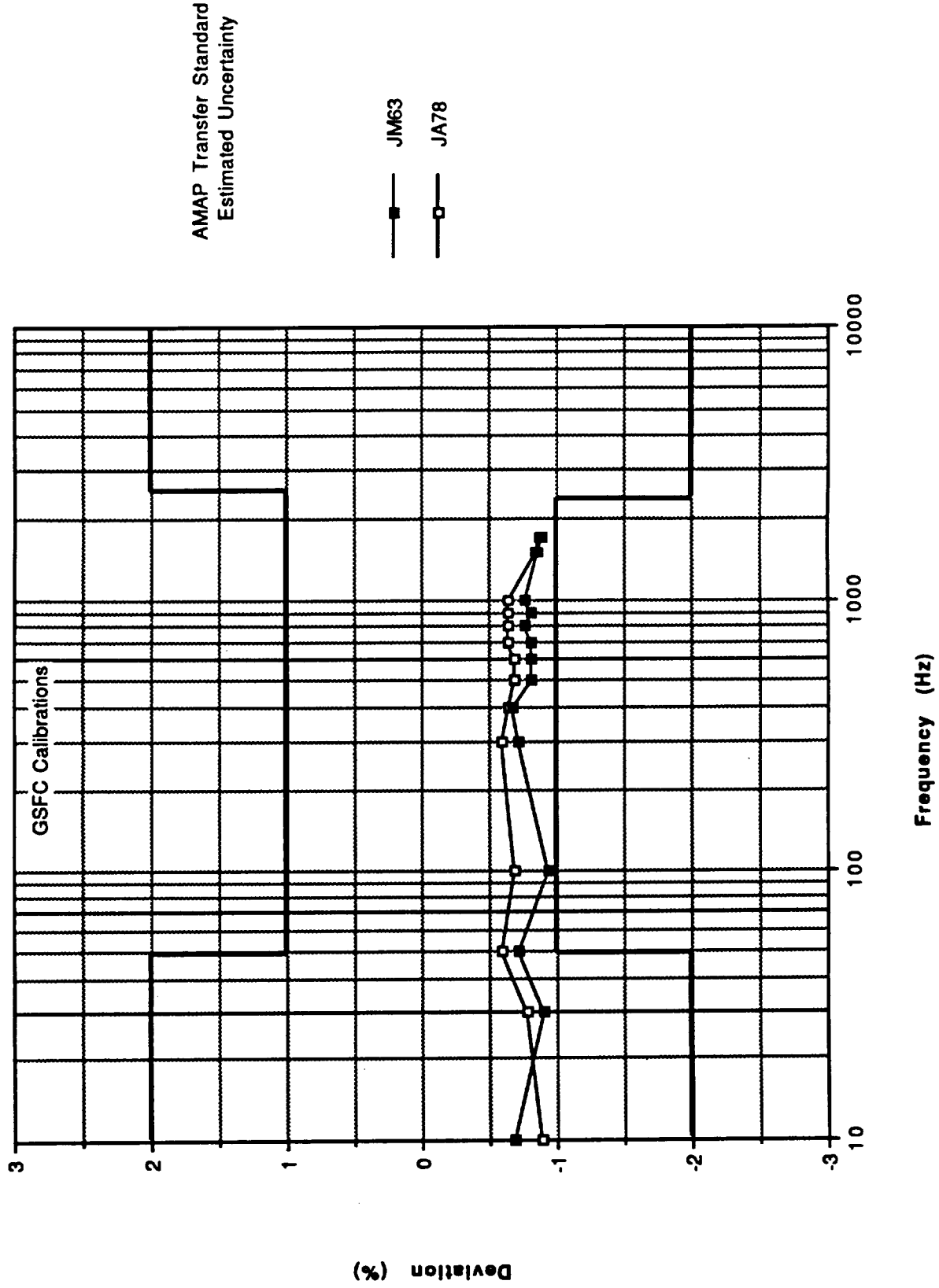


Figure 2

# NASA Metrology Working Group Acceleration Measurement Assurance Program

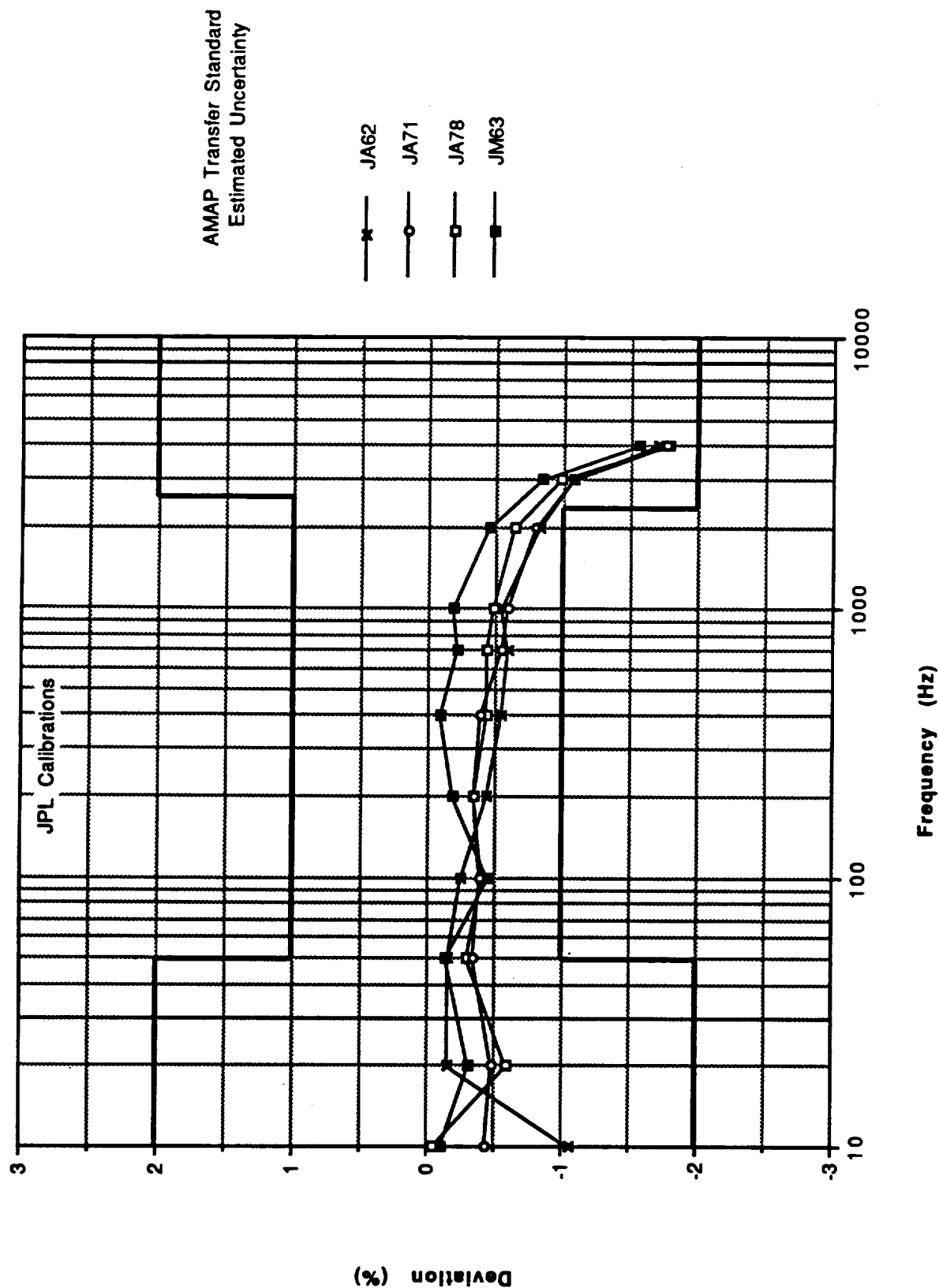


Figure 3



# NASA Metrology Working Group Acceleration Measurement Assurance Program

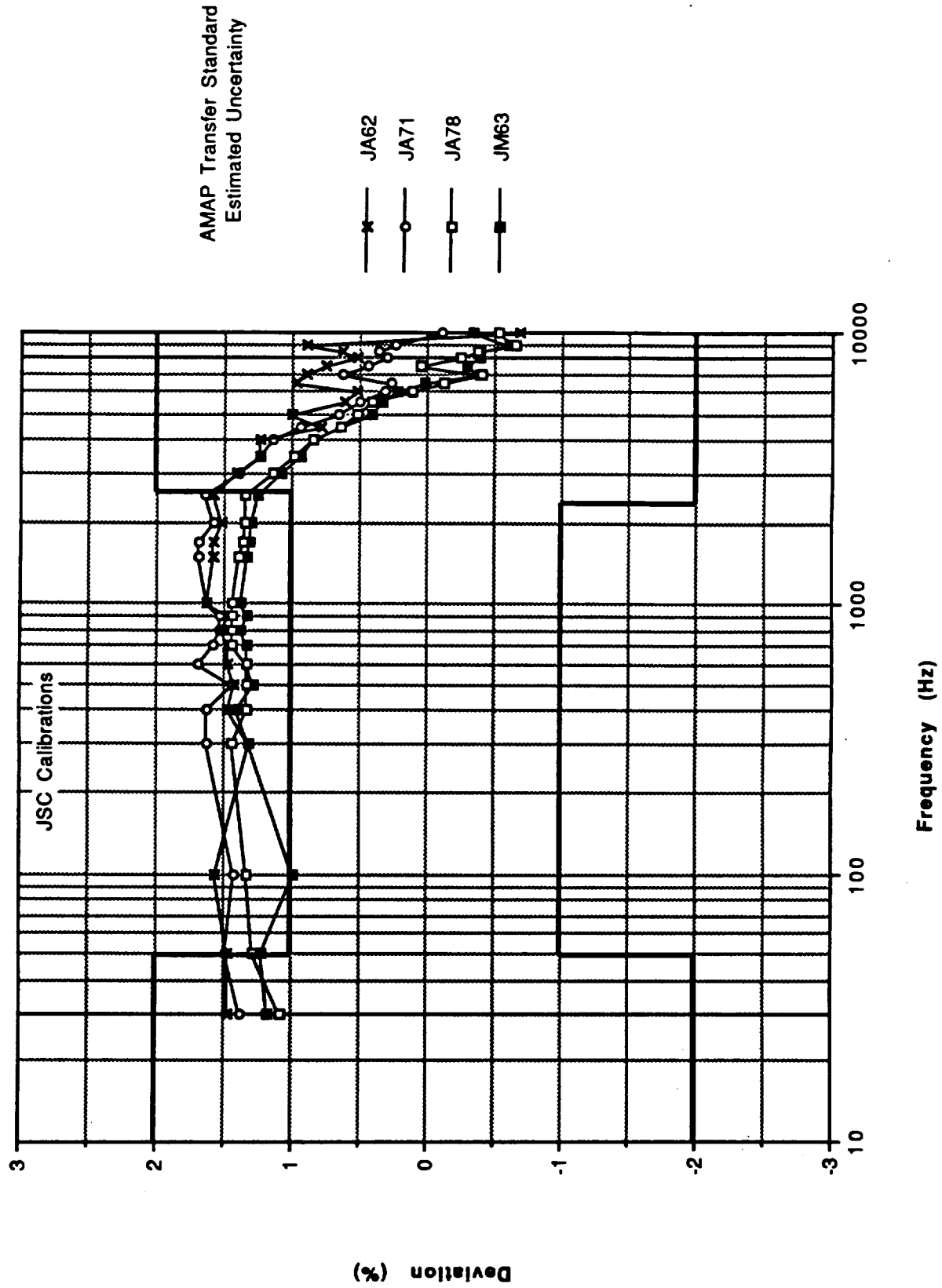


Figure 4

# NASA Metrology Working Group Acceleration Measurement Assurance Program

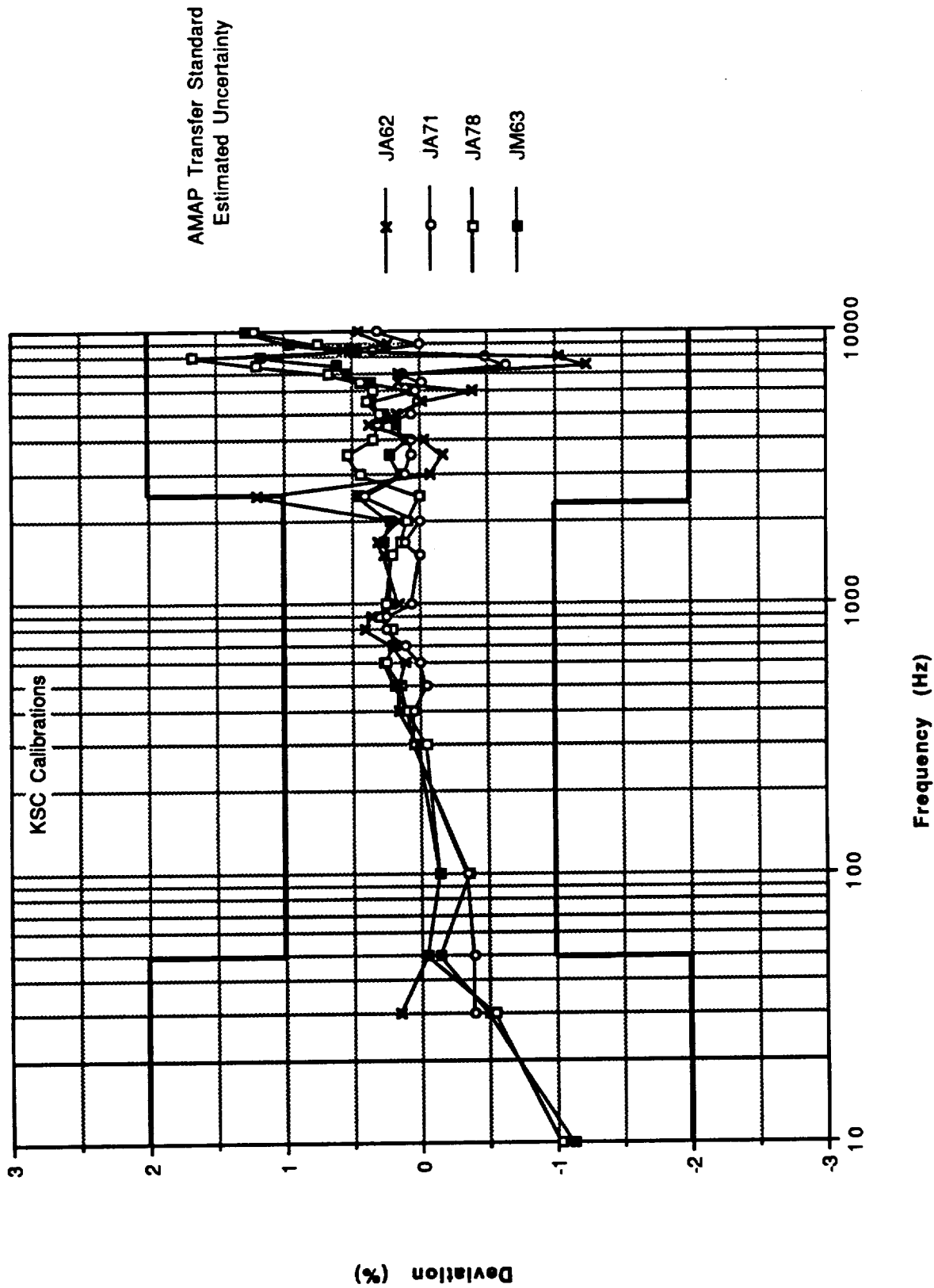


Figure 5

C-4

NASA Metrology Working Group  
Acceleration Measurement Assurance Program

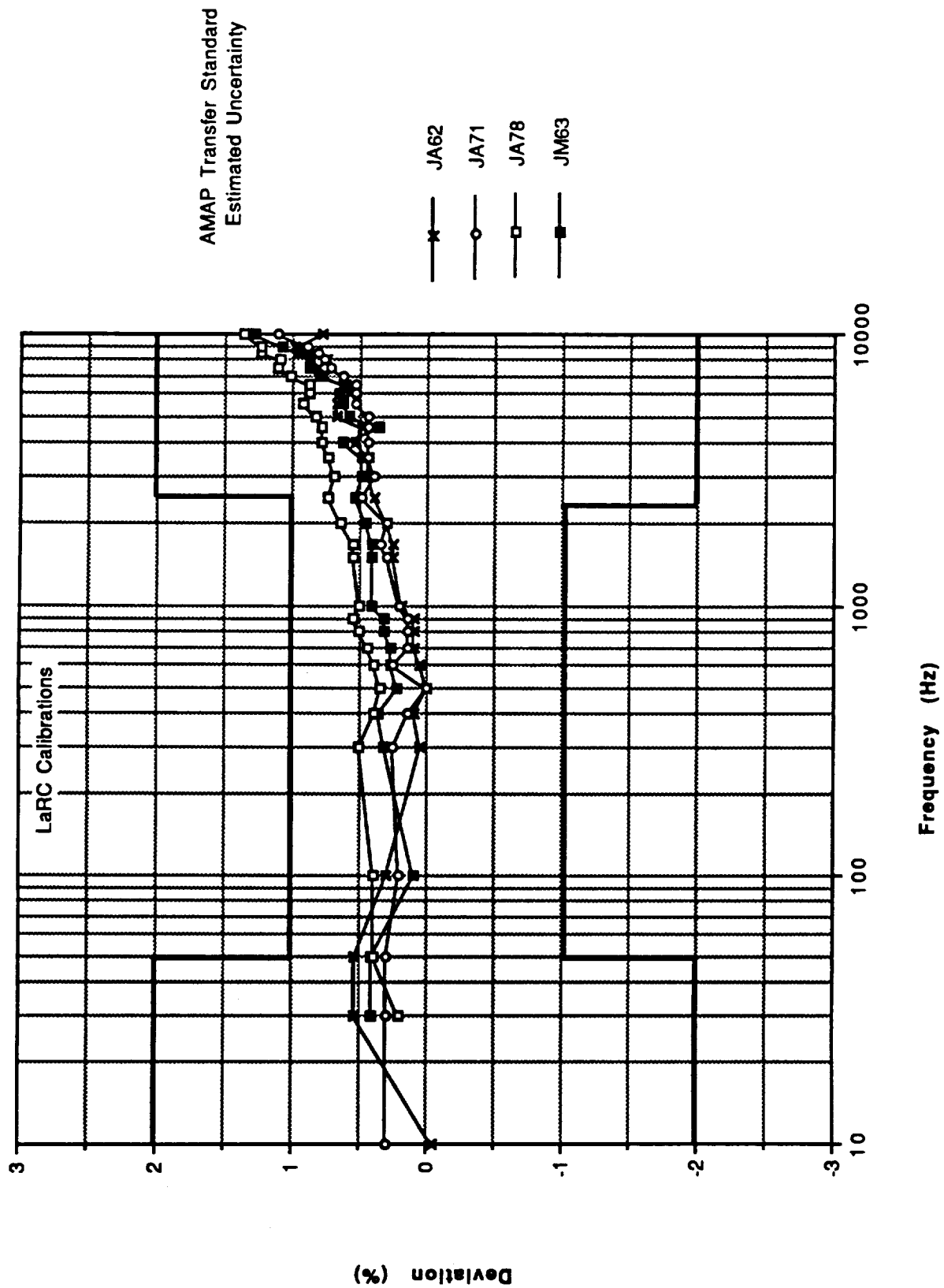


Figure 6

# NASA Metrology Working Group Acceleration Measurement Assurance Program

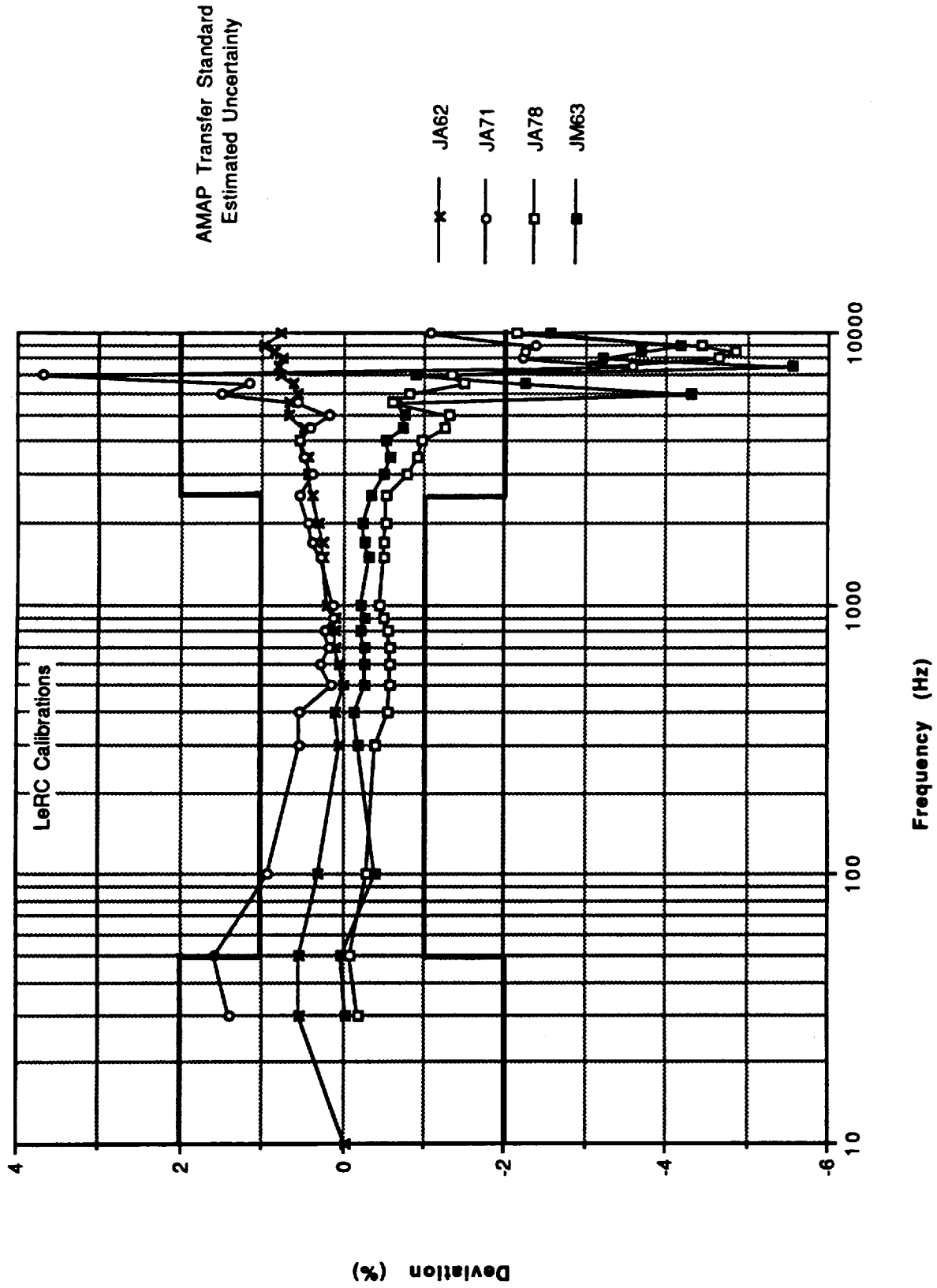


Figure 7

# NASA Metrology Working Group Acceleration Measurement Assurance Program

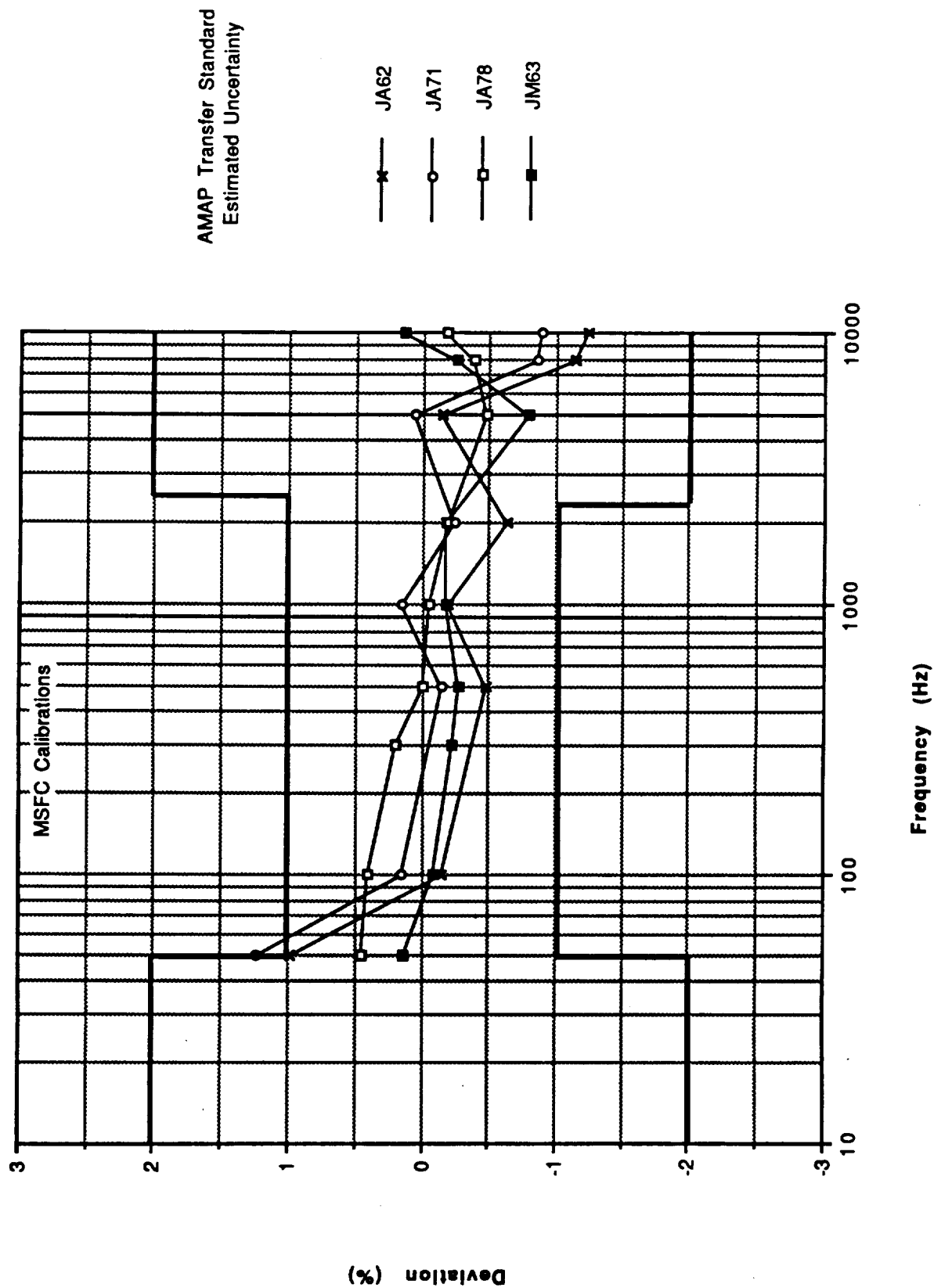


Figure 8

# NASA Metrology Working Group Acceleration Measurement Assurance Program

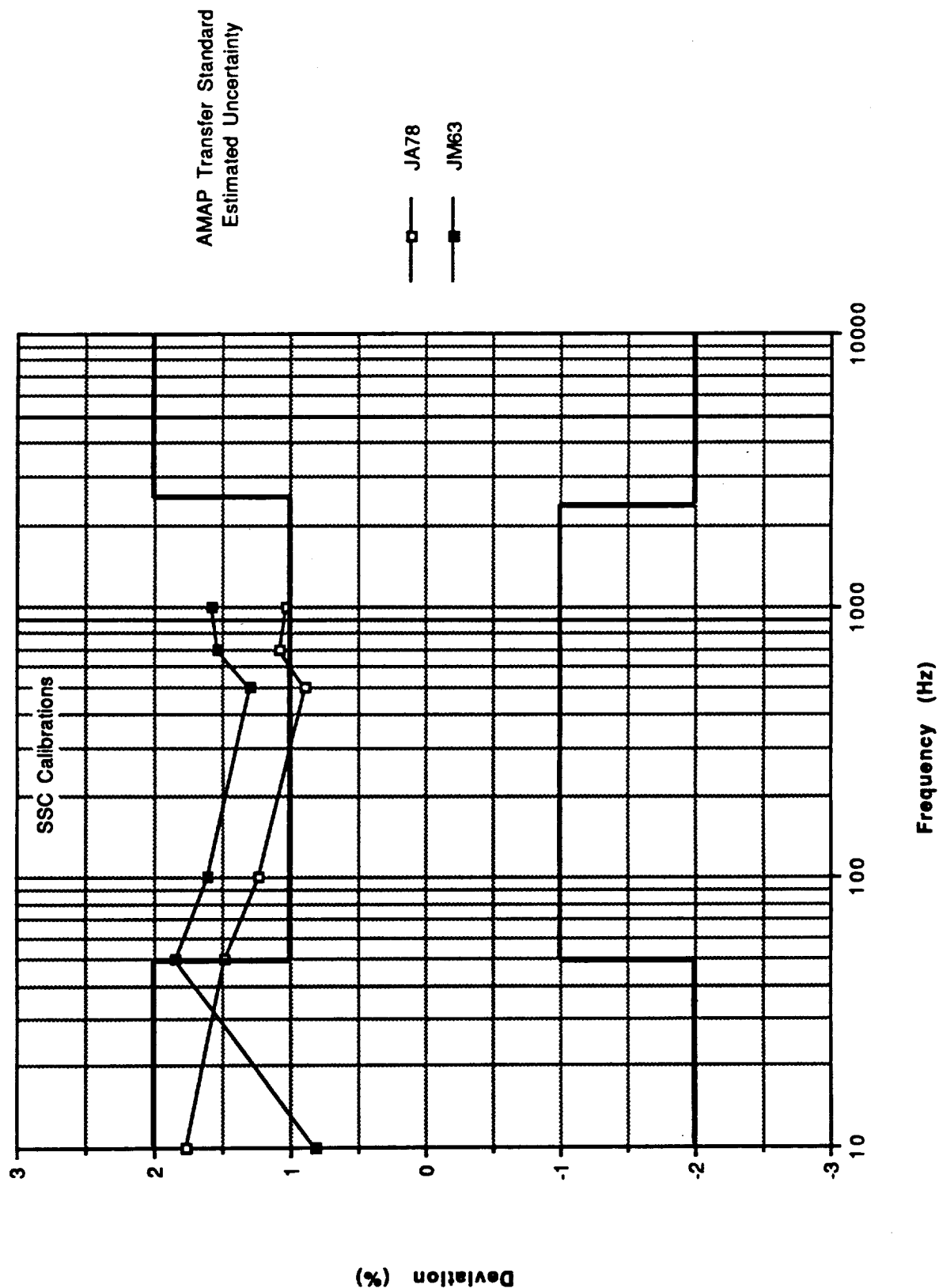


Figure 9

Youden Diag.am  
JA62 vs JA71

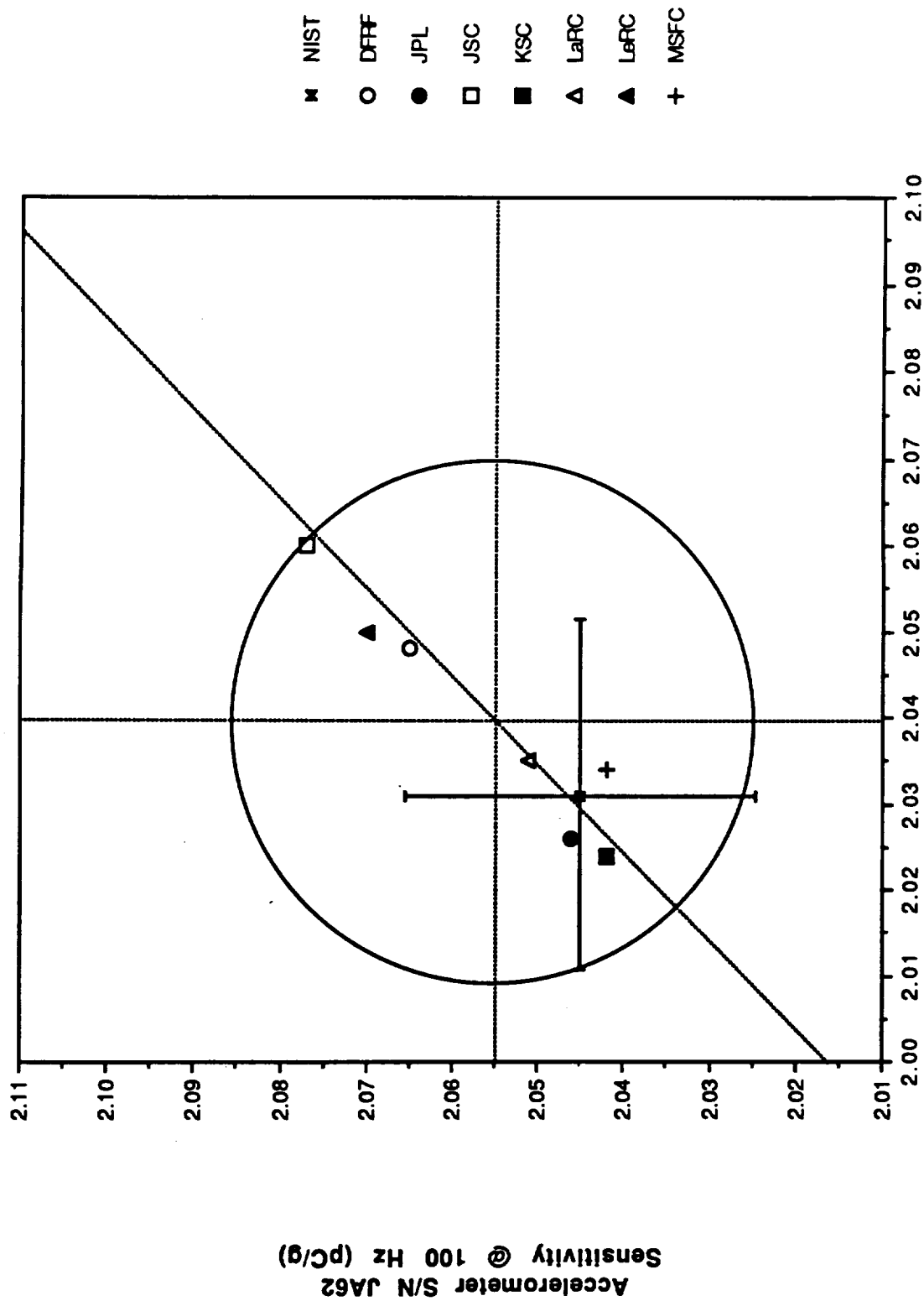


Figure 10

# Youden Diagram JA78 vs JM63

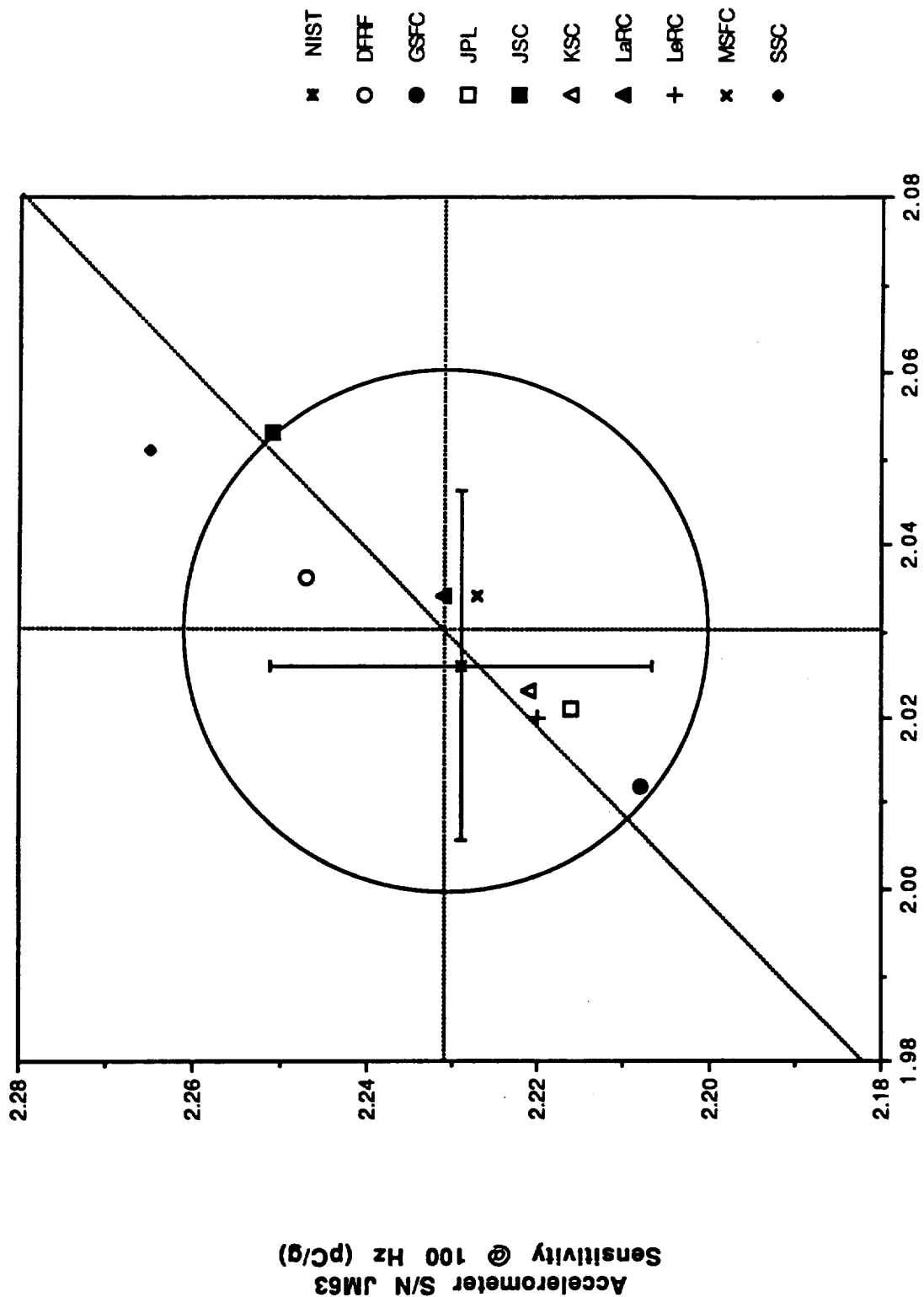


Figure 11



VOLT MEASUREMENT ASSURANCE PROGRAM

1993 STATUS REPORT

Kristen J. Riley

Engineering, Energy and Laboratory Management Branch  
John F. Kennedy Space Center

16th Annual NASA Metrology and Calibration Workshop  
Rockville, Maryland

April 20-22, 1993

## Volt Measurement Assurance Program

### Background

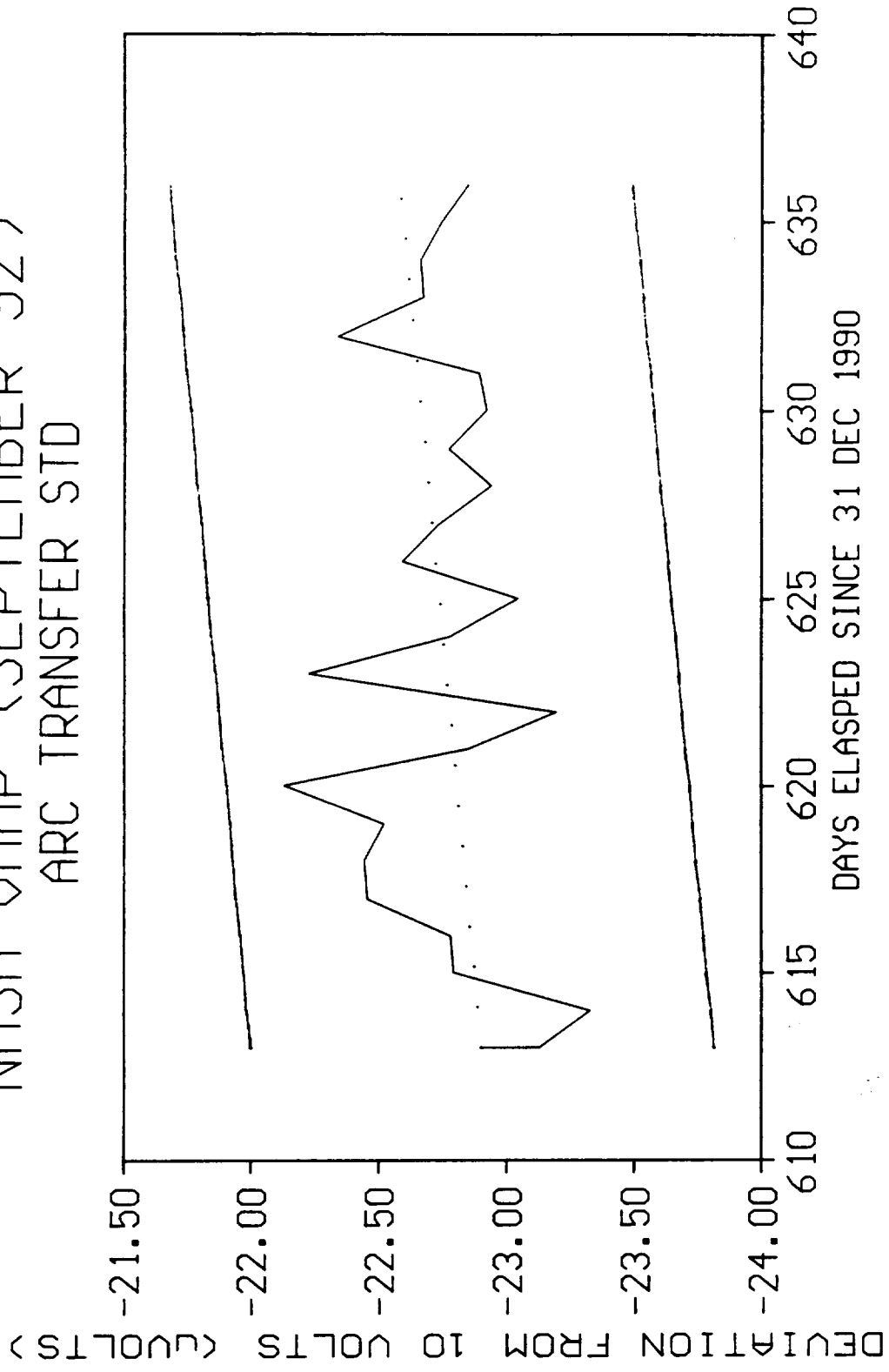
Solid-State Voltage References (SSVR) are increasing in popularity and use throughout the NASA environment. Conventional test service requires each center to obtain and ship transfer standards to the National Institute of Standards and Technology (NIST) for comparison. This is a costly and time consuming process. Measurement Assurance Programs (MAPs), which establish traceability to NIST and validate the measurement process by which field installations obtain and document traceability to national standards, are being developed as an alternative to the conventional test service. NIST has developed various MAPs for which NASA participates. However, NIST does not offer a MAP service for SSVRs. The need for an automated measurement system capable of establishing, maintaining, and disseminating the Volt at the 10 volt level internal to NASA was required for improved laboratory operations and measurement processes, with cost savings and shorter turnaround times.

The NASA Volt Measurement Assurance Program was developed with automated capability to maintain the NASA legal representation of the U. S. volt using a 10 volt solid-state source to ensure measurement traceability between field installations. Two pivot laboratories were established, one at Kennedy Space Center and the other at Ames Research Center, with identical automated systems and software. MAP procedures were developed and distributed to the participating field installations, and pivot laboratory traceability to NIST was established.

### Status

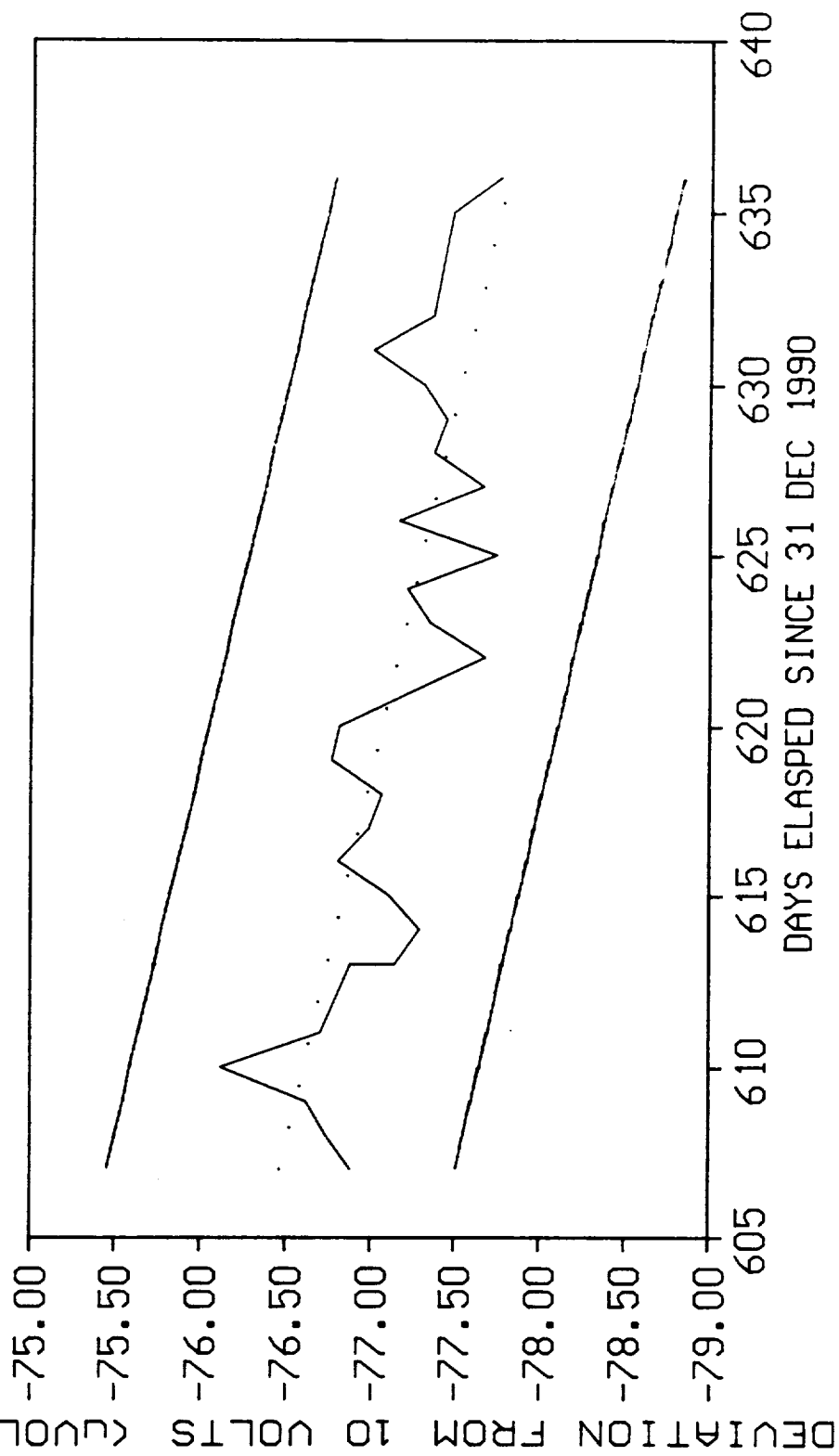
The Volt MAP is currently operational with eleven field installations participating. Validation of each installation's measurement process including procedures, test equipment, data analysis, laboratory environment, and personnel is in progress through this MAP. Both the installation's calibration error and differences between installations have been quantified, NASA's dependence on NIST has been minimized, and the NASA metrology infrastructure has been enhanced through cooperative activity. The enclosed graphs show the drift rates of solid state voltage references for participants involved with the east coast pivot laboratory.

NASA UMAP (SEPTEMBER 92)  
ARC TRANSFER STD



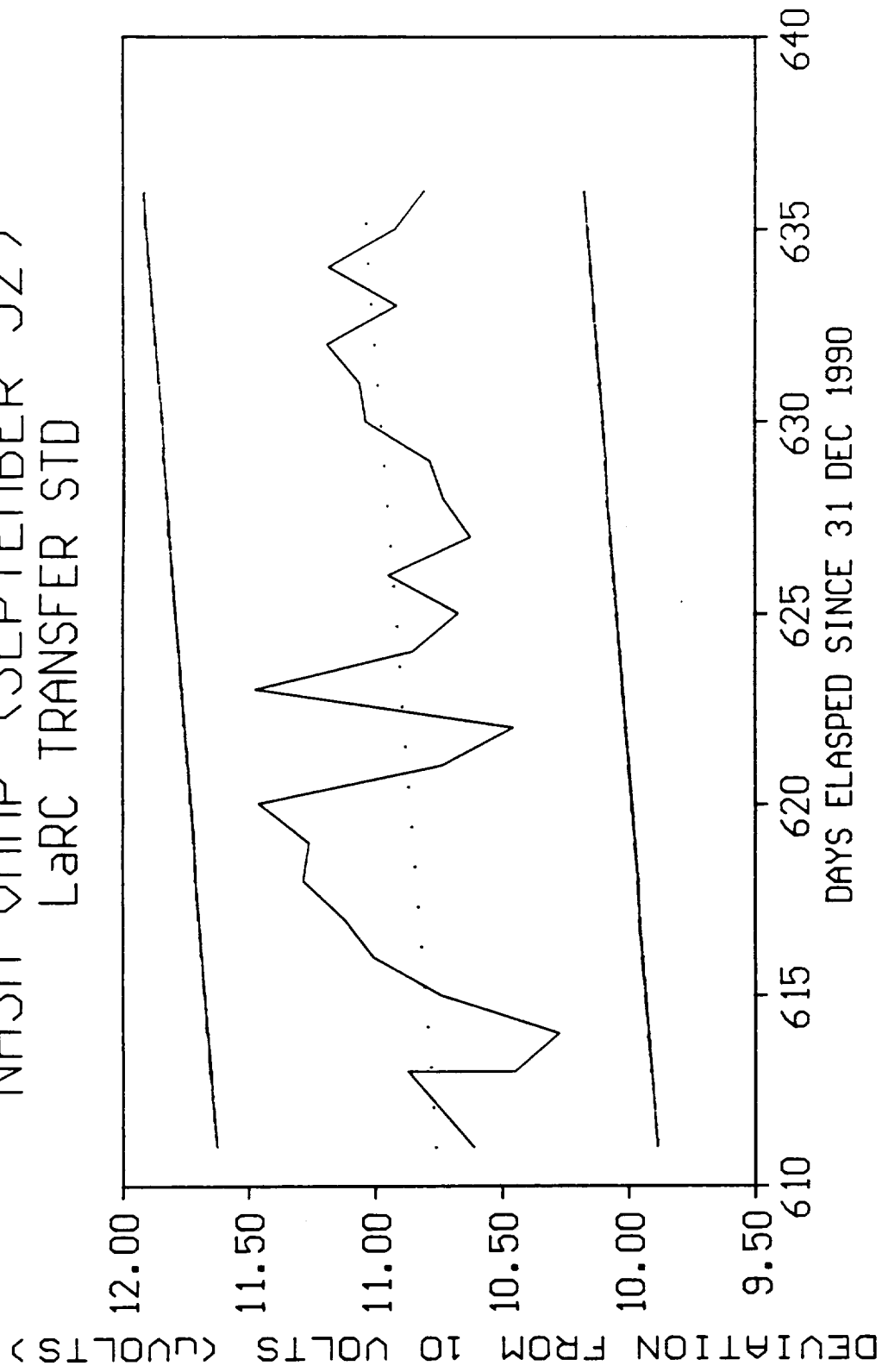
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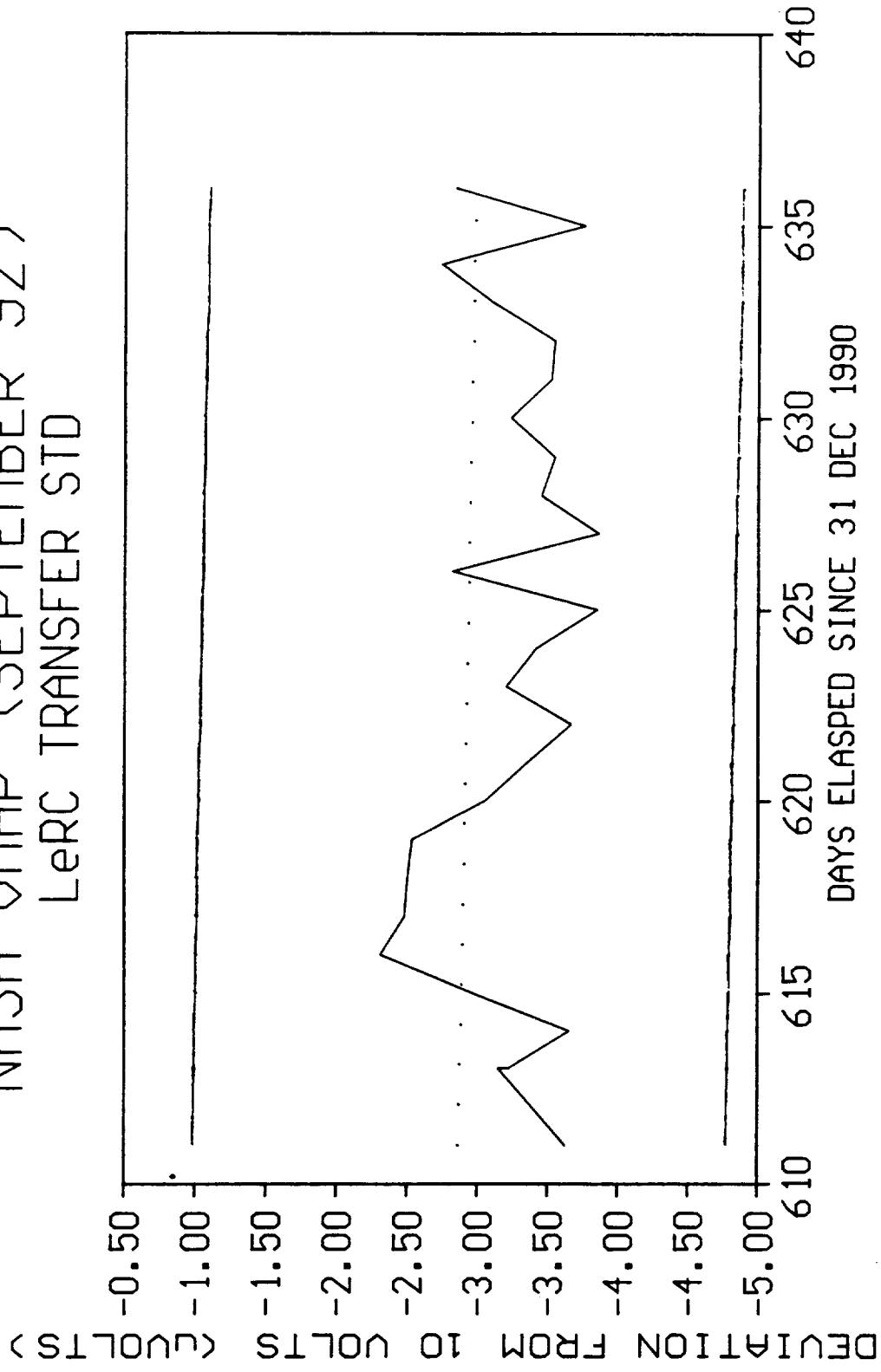


— OBSERVED    ··· PREDICTED    --- LL

NASA UMAP (SEPTEMBER 92)  
LaRC TRANSFER STD

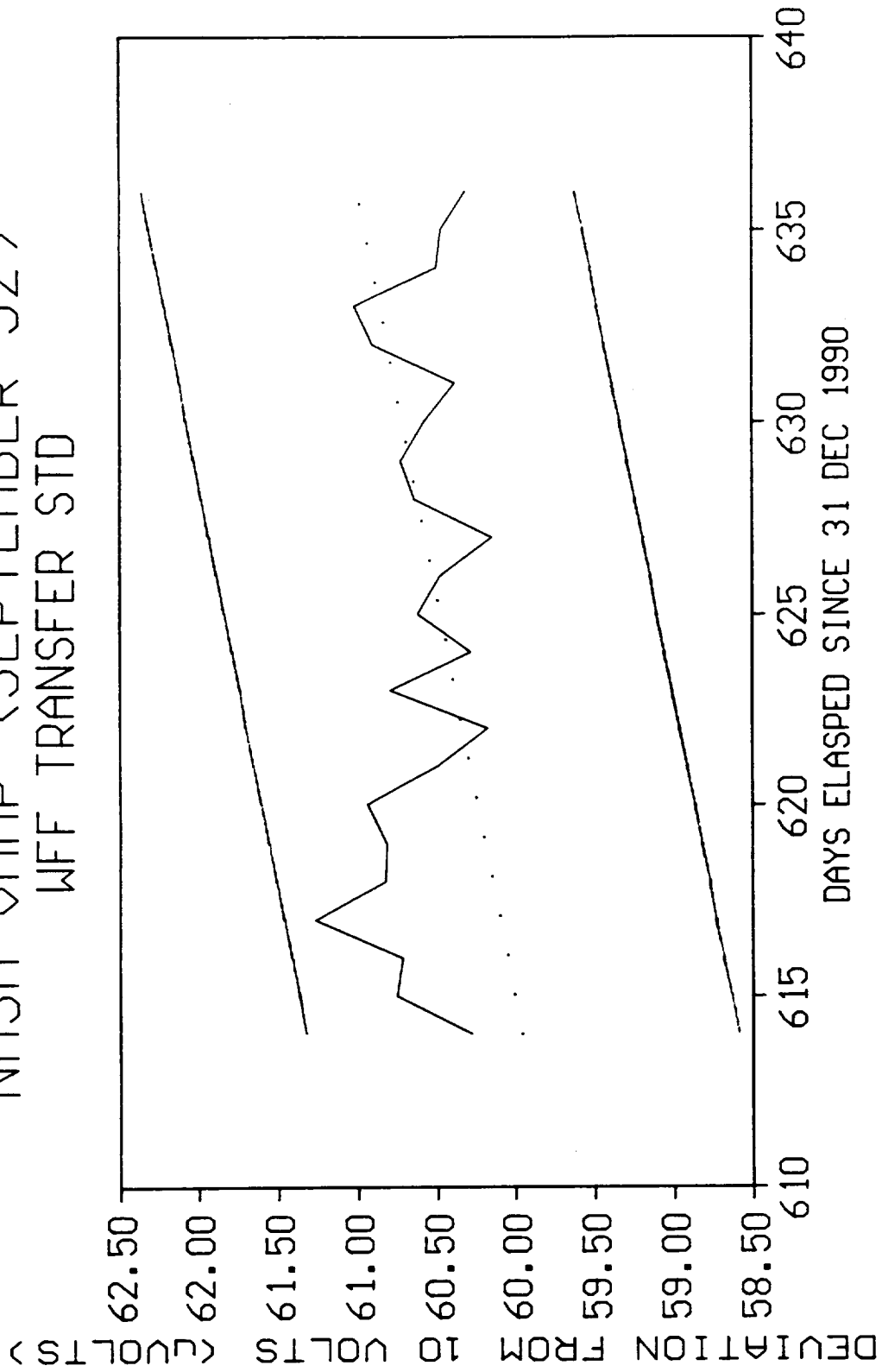


NASA UMAP (SEPTEMBER 92)  
LERC TRANSFER STD



— OBSERVED    ··· PREDICTED    — LL

NASA UMAP (SEPTEMBER 92)  
WFF TRANSFER STD



— OBSERVED    ··· PREDICTED    --- UL    ---- LL





# VOLT MEASUREMENT ASSURANCE PROGRAM

Kristen J. Riley  
Kennedy Space Center

16th Annual Nasa Metrology and Calibration Workshop

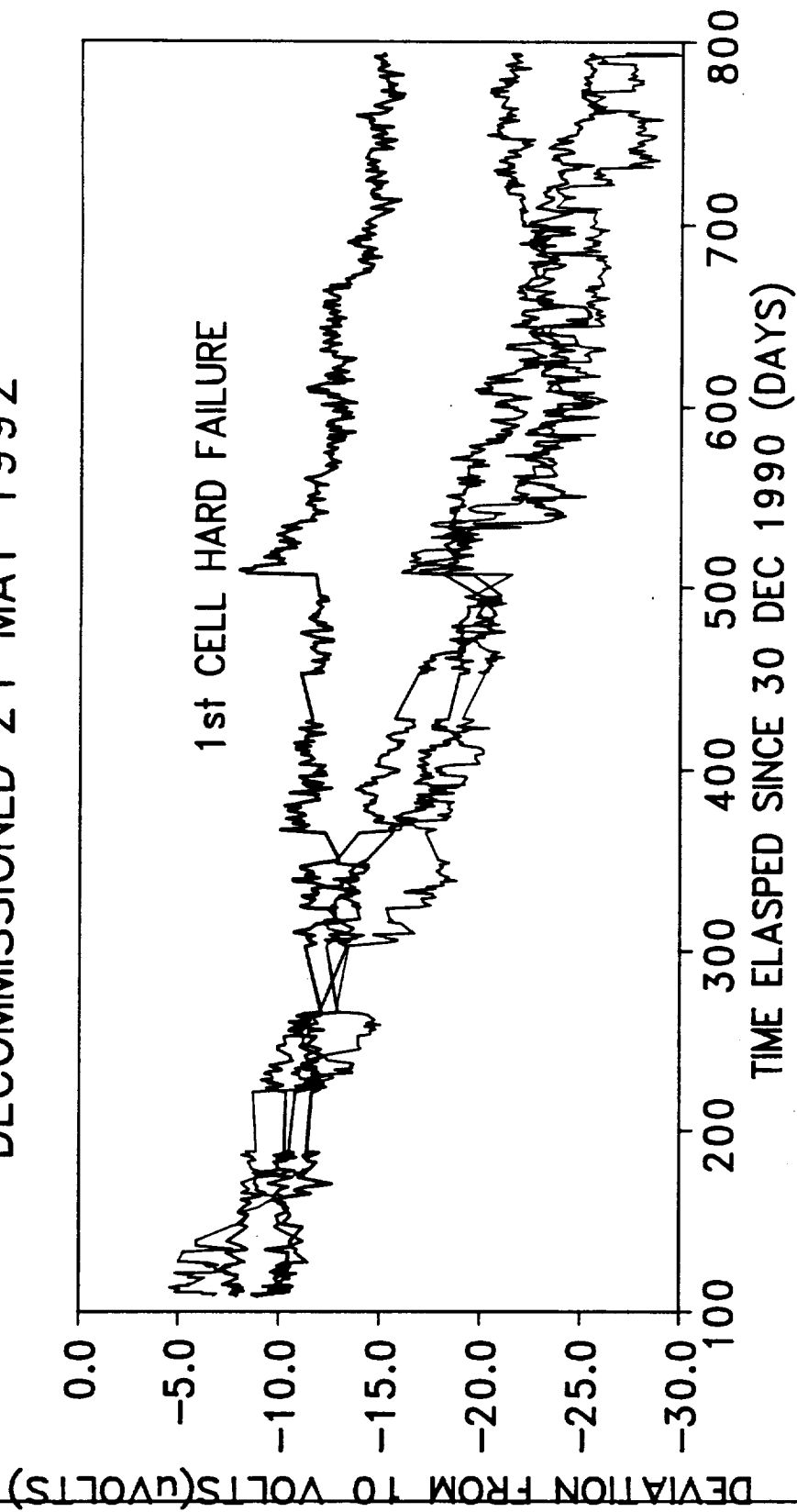
# STATUS

- May 1992 – Datron 4911 Decommissioned  
as KSC Reference
- September 1992 – East Coast VMAP  
Intercomparison
- April 1993 – West Coast VMAP  
Intercomparison
- May 1993 – East Coast VMAP  
Intercomparison

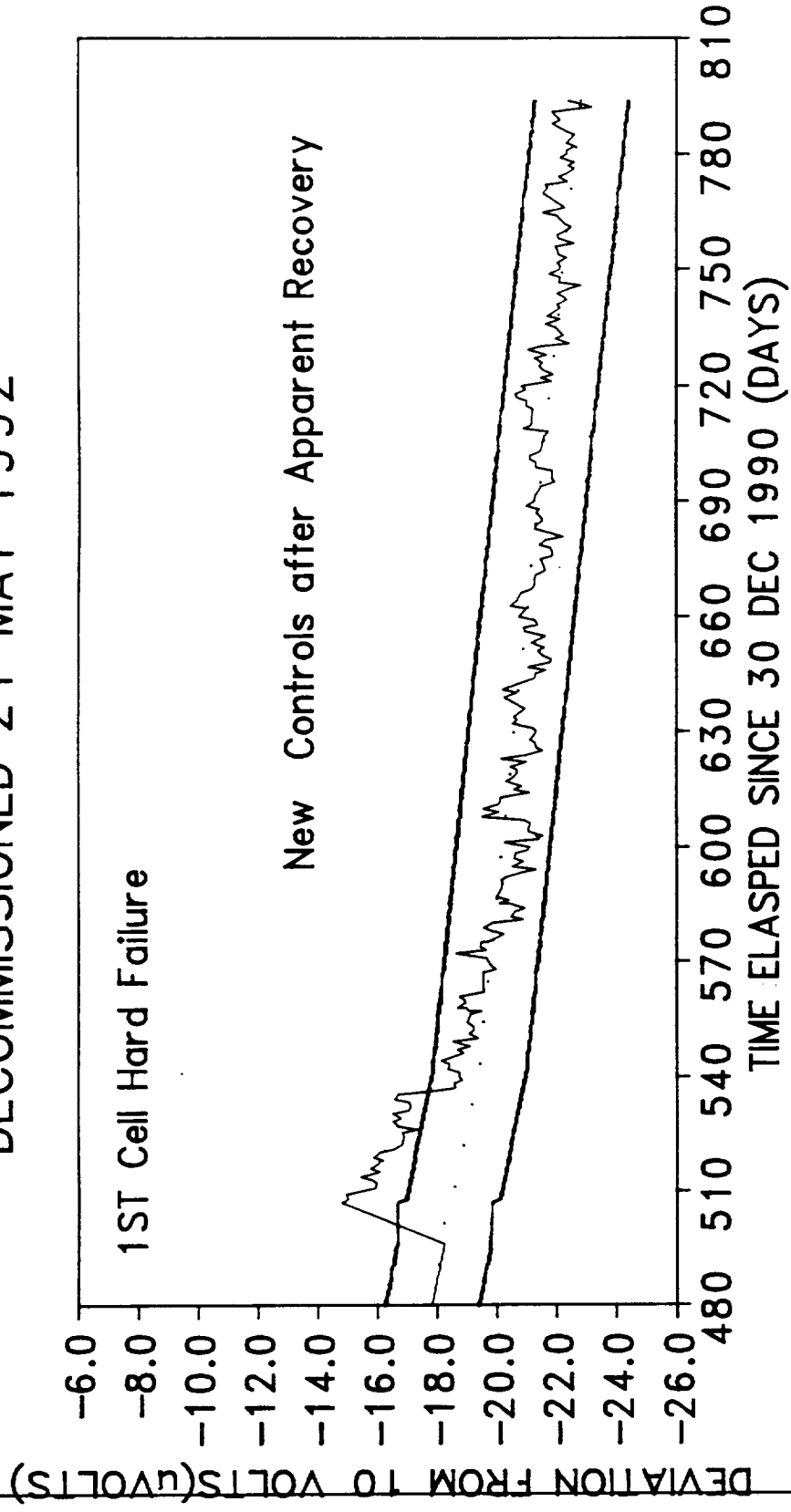
# STATUS CONTINUED

- Revision of VMAP Software Program
  - Completion Expected June 1993

DATRON 4911  
DECOMMISSIONED 21 MAY 1992



DATRON 4911  
DECOMMISSIONED 21 MAY 1992



— OBSERVED — PREDICTED — LL — UL



TMAP PHASE I RESULTS  
NASA METROLOGY WORKSHOP

APRIL 22, 1993

TONY SAPPINGTON

## **SCHEDULING PROBLEMS**

- **PLANNED COMPLETION DATE - AUGUST 1992**
- **ACTUAL COMPLETION DATE - JANUARY 1993**
- **TURNAROUND TIME OF PARTICIPANTS WAS MUCH LONGER THAN SCHEDULED**
- **THREE WEEKS ACTUAL VS TWO WEEKS SCHEDULED**

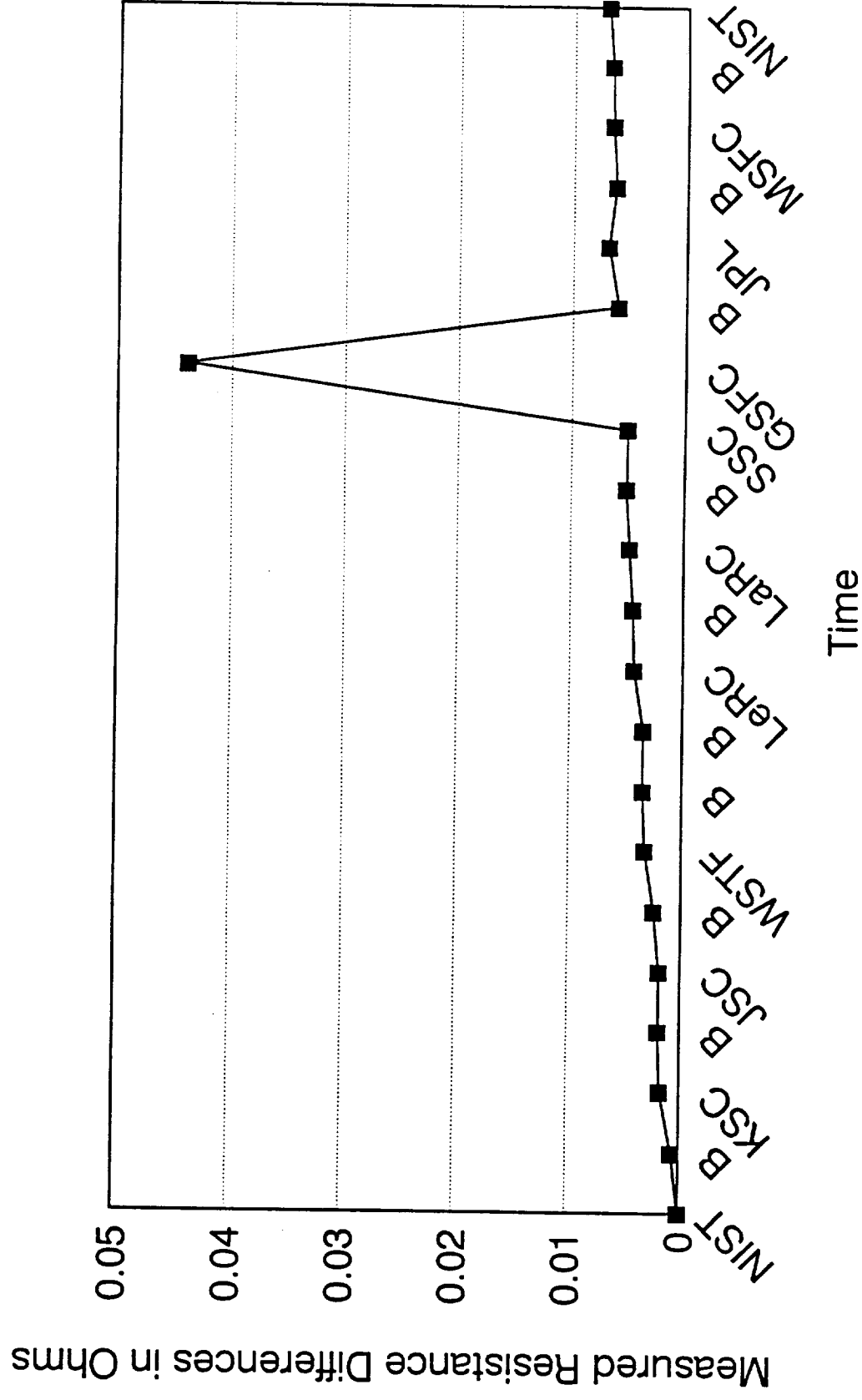


## RESULTS OF TMAP PHASE I

- SHIPPING EFFECTS WERE GREATER THAN EXPECTED ON THE SPRT'S
  - THIS MADE ANY RIGOROUS DATA ANALYSIS IMPOSSIBLE.
- MORE EMPHASIS MUST BE MADE BY PARTICIPANTS TO STAY ON THE ORIGINAL SCHEDULE
- ONE PARTICIPANT WAS FOUND TO HAVE PROBLEMS
  - THEY WERE NOTIFIED AND CORRECTIVE ACTION TAKEN.
- THIS PHASE WAS SUCCESSFUL AS IT FLAGGED PROBLEMS WITH A PARTICIPANT, AND IT LAYED A SOLID FOUNDATION FOR FURTHER TMAP PHASES.

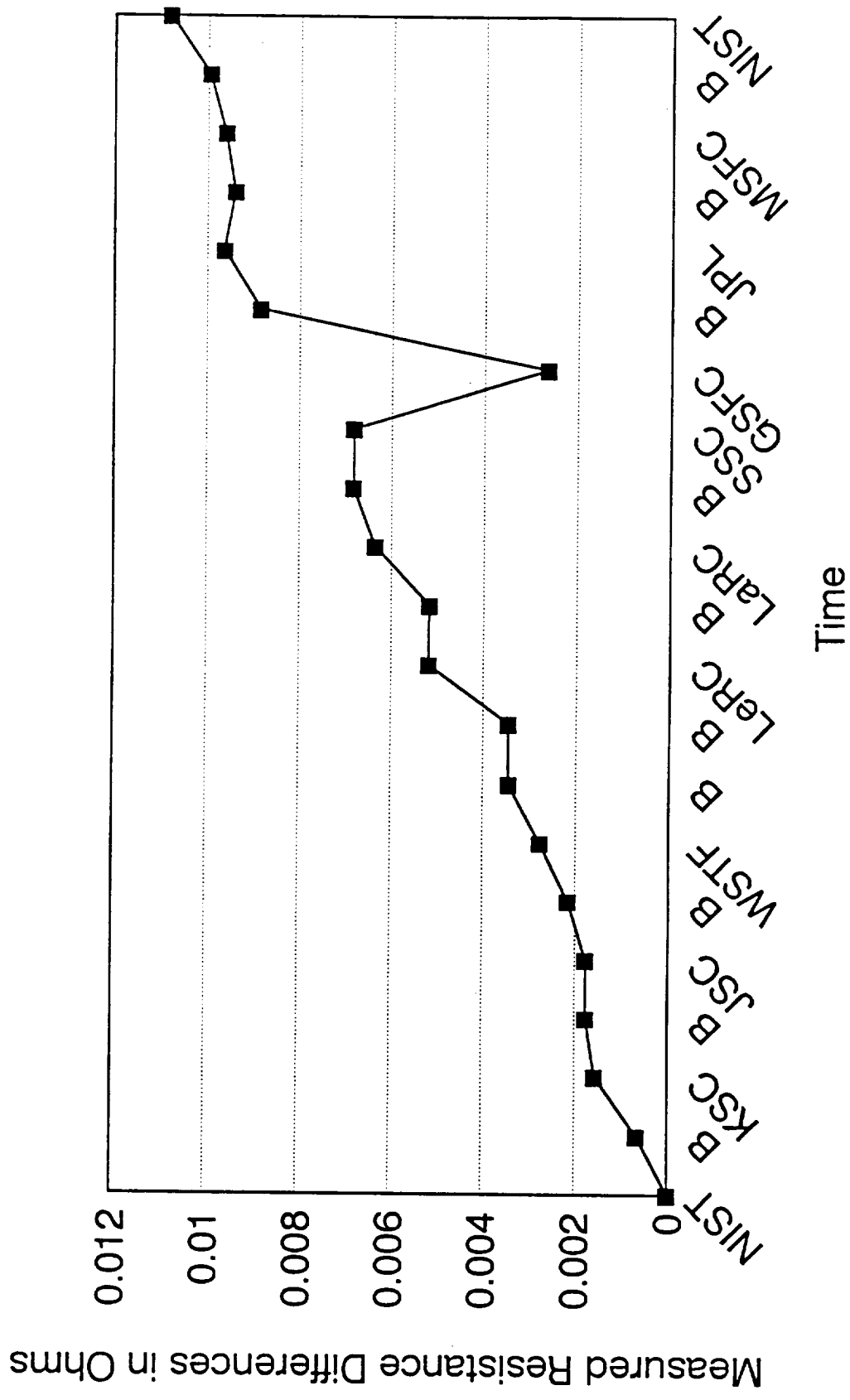
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## TPW RESISTANCE MEASUREMENT



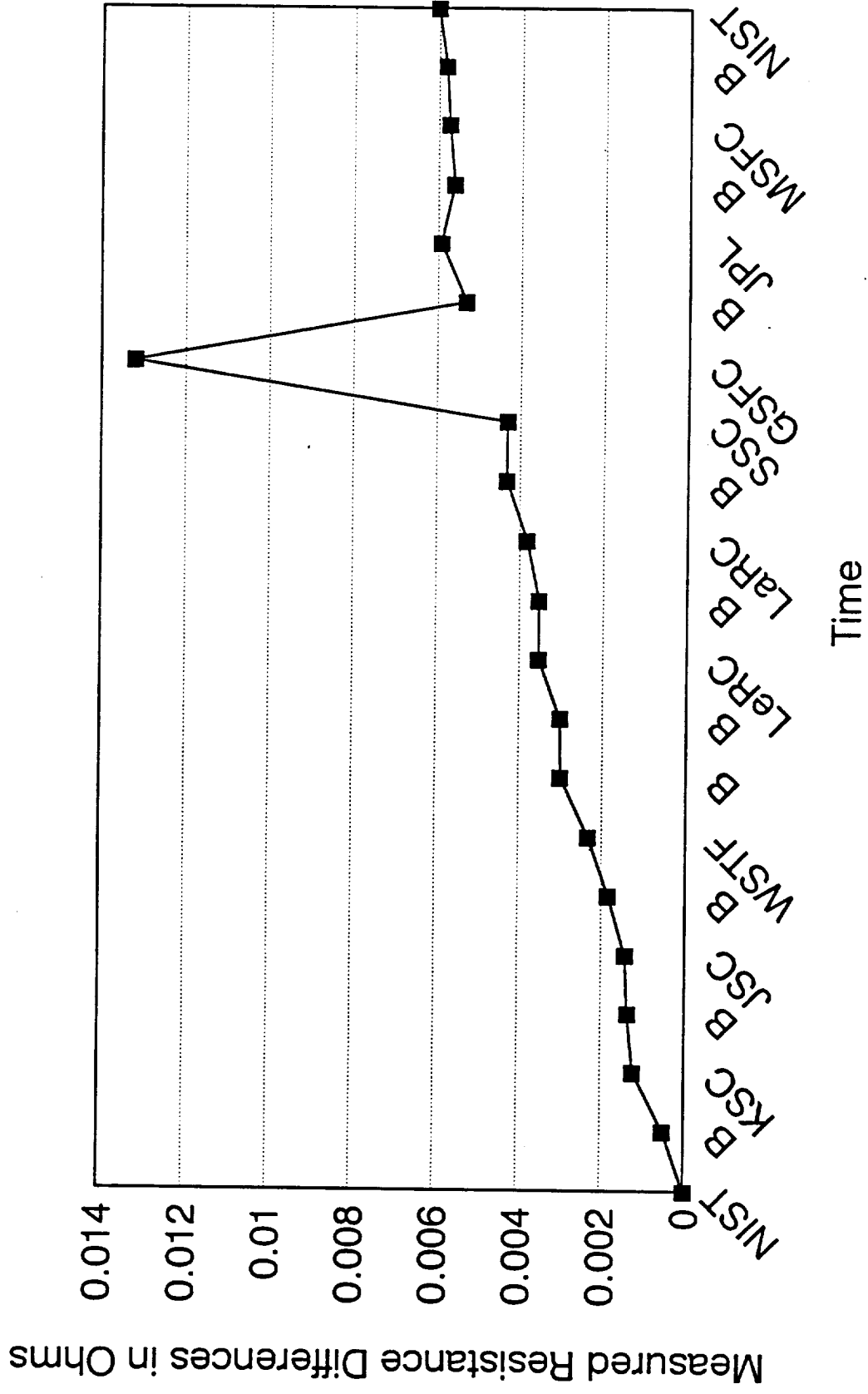
# SPRT 365

## TPW RESISTANCE MEASUREMENT



# SPRT 366

## TPW RESISTANCE MEASUREMENT



## **WHERE WE ARE NOW**

- **MINI ROUND-ROBIN HAS BEEN CANCELLED**
- **ONE ARTIFACT WAS BROKEN DUE TO ACCUMULATIVE SHIPPING EFFECTS**
- **STUDY OF ANNEALING OUR ARTIFACTS - TEMPERATURE AND DURATIONS**
- **PROCUREMENT OF THE FINEST ROSEMOUNT SPRT**
- **READY FOR TMAP PHASE II**
- **LOOKING FOR NON-STANDARD TEMPERATURE POINT FREEZING CELL FOR TMAP PHASE III**

# Standard Temperature Point Capabilities By NASA Center

NASA CENTER	Cryogenic Comparator	Available N2	Ar	O2	Mercury Triple Point	Water Triple Point	Gallium Cell	FREEZING CELLS	TIN	ZINC
-------------	----------------------	--------------	----	----	----------------------	--------------------	--------------	----------------	-----	------

ARC	X	Not interested in participating						NO	NO	NO
		Y	N	N	Y	YES	YES			
<u>GSFC*</u>		Y	N	N	Y	YES	YES	NO	NO	NO
<u>JPL</u>	YES	Y	Y	Y	Y	NO	YES	NO	NO	YES
<u>JSC</u>	YES	Y	?	N	N	NO	YES	NO	YES	YES
<u>LaRC</u>	X	Y	?	N	Y	YES	YES	NO	YES	YES
<u>MSFC</u>	YES	Y	Y	N	Y	YES	YES	YES	YES	YES
<u>LeRC*</u>	X	Y	Y	Y	Y	NO	YES	NO	NO	NO
<u>WSTF</u>	YES	Y	?	Y	Y	YES	YES	NO	YES	YES
<u>KSC</u>	X	Y	Y	N	Y	YES	YES	YES	YES	YES
<u>SSC</u>	YES	Y	Y	Y	Y	YES	YES	YES	YES	YES

TEMP IN KELVIN	77	87	90	234	273	303	505	693
----------------	----	----	----	-----	-----	-----	-----	-----

TEMP IN CELSIUS	-197	-187	-293	-39	0.01	30	232	420
-----------------	------	------	------	-----	------	----	-----	-----

\* No Annealing Capability

## TMAP PHASE II PLANS

- SAME ROUND ROBIN STYLE TPW RESISTANCE MEASUREMENT
- PARTICIPANTS WILL TPW, FULLY ANNEAL, TPW
- WILL USE TWO ORIGINAL ARTIFACTS AND ONE FROM ROSEMOUNT
- 1 AND 2mA CURRENTS WILL BE USED, BUT WITH REDUCED DATA TAKING REQUIREMENTS OF PARTICIPANTS

# TMAP PLANNED FUNDING AS OF APRIL, 1993

- FY93 30K
- FY94 20K
- FY95 20K



**JOHNSON SPACE CENTER  
MEASUREMENT STANDARDS AND CALIBRATION LABORATORY  
RESEARCH AND TECHNOLOGY OBJECTIVE AND PLAN**

**FIBER OPTIC POWER MAP  
HISTORY AND STATUS REPORT**

**PREPARED AND PRESENTED BY:  
W. T. MCPETERS  
SIMCO ELECTRONICS  
APRIL 20-22, 1993**

# **FY1992 JSC/MSCL FIBER OPTIC POWER MAP PROGRAM**

## **PROGRAM DESCRIPTION AND PHASED APPROACH**

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- THE JSC SPONSORED FIBER OPTIC POWER MEASUREMENT ASSURANCE PROGRAM STARTED MAY 1, 1989.

- JSC FOMAP IS A FOUR PHASE PROGRAM

- PHASE ONE:

INTEREST SURVEY  
STANDARD PROCUREMENT AND DELIVERY  
TRAINING

- PHASE TWO:

REFERENCE STANDARDS PROCUREMENT  
MAP PROCEDURE DEVELOPMENT  
TRANSPORT STD. PROCUREMENT AND CHECKOUT  
MAP PROCESS DEVELOPMENT

- PHASE THREE:

PARTICIPANT TESTING  
DATA REDUCTION  
REPORT GENERATION

- PHASE FOUR:

PROGRAM REVIEW

- PROGRAM CURRENTLY OPERATING IN PHASE THREE

STATUS REPORT - APRIL 20-22, 1993

# **FY 1992 JSC/MSCL FIBER OPTIC POWER MAP PROGRAM**

## **PHASED APPROACH**

---

- **PHASE ONE:**
- **INTEREST SURVEY - FORMAL QUESTIONNAIRE PREPARED AND MAILED TO ALL NASA CENTER METROLOGY OPERATIONS  
ALL RESPONDED.  
TWO (PLUS ONE LATER) CHOSE TO PARTICIPATE**
  - 1. KENNEDY SPACE CENTER (KSC)**
  - 2. DRYDEN FLIGHT RESEARCH FACILITY (DFRF)**
  - 3. JET PROPULSION LABORATORY (JPL)**
- **STANDARD PROCUREMENT AND DELIVERY - COMPLETED PROCUREMENT OF AND RECEIVED ANRITSU FIBER OPTIC POWER CALIBRATION SYSTEM. TOTAL COST: APPROXIMATELY \$125K.**
- **TRAINING - RECEIVED TRAINING FROM NIST AT BOULDER, COLORADO AT A COST OF \$1.7K.  
RECEIVED TRAINING FROM ANRITSU IN THE OPERATION OF THEIR SYSTEM.  
(COST WAS PART OF ORIGINAL PURCHASE PRICE)**

**STATUS REPORT - APRIL 20-22, 1993**

# FY 1992 JSC/MSCL FIBER OPTIC POWER MAP PROGRAM

## PHASED APPROACH

---

- PHASE TWO:
- REFERENCE STANDARDS PROCUREMENT - PURCHASED LASER PRECISION, MODEL RS 5900, ELECTRICALLY CALIBRATED PYRO-ELECTRIC RADIOMETER (ECPR) AT A COST \$8.6K.
- MAP PROCEDURE DEVELOPMENT - DEVELOPED MAP OPERATIONAL PROCESS PROCEDURE REFERENCING RECOMMENDATIONS PROVIDED BY NIST.
- TRANSPORT STANDARD PROCUREMENT AND CHECKOUT - CANDIDATE TRANSPORT STANDARD POWER METERS PURCHASED FROM:
  - PHOTODYNE / \$2.5k
  - LASER PRECISION / \$3.9K
  - HEWLETT PACKARD / \$8.2KSYSTEM ACCESSORIES PROCUREMENT AND CHECKOUT:
  - INFRARED BEAM COLLIMATORS / \$1.7K
  - INFRARED SENSOR CARD / \$0.1K
  - 850 nm FIBER OPTIC SOURCE / \$3.9K
  - 1300 nm FIBER OPTIC SOURCE / \$5.0K
  - 850 nm AND 1300 nm POWER SPLITTERS / #3.8K
  - OPTICAL TABLE (4 FT. BY 12 FT.) / \$15.0K
  - OPTICAL RAIL SYSTEM / \$4.0K
  - VARIOUS SET-UP ACCESSORIES / \$12.9K
- MAP PROCESS DEVELOPMENT - TEST ALL STANDARDS, SOURCES AND ACCESSORIES - DEVELOP PROCEDURE FOR USE BY PARTICIPANTS

STATUS REPORT - APRIL 20-22, 1992

# **FY 1992 JSC/MSCL FIBER OPTIC POWER MAP PROGRAM**

## **PHASED APPROACH**

---

- **PHASE THREE:**
- **TRANSPORT PACKAGE PREPARATION FOR PARTICIPANT TESTING:**
  - FIRST: OBTAINED NIST CERTIFICATION OF REF. STD. ECPR / \$1.9K**
  - SECOND: PARTICIPATED IN NIST FIBER OPTIC MAP COMPARING**  
**NIST TRANSPORT STD. TO POTENTIAL JSC TRANSPORT**  
**STANDARD / \$1.8K**
  - THIRD: COMPARED JSC FIBER OPTIC CHECK STANDARD TO JSC**  
**TRANSPORT STANDARD**
- **SHIPPED JSC FOMAP TRANSPORT STANDARD PACKAGE TO KSC - MAY 1992**
- **KSC PARTICIPATION COMPLETED AND REPORT FURNISHED BY JULY 1992**
- **CONTACTED SECOND PARTICIPANT (DFRF) - JUNE 1992**
- **TRANSPORT STANDARD PACKAGED PROVIDED TO DFRF - SEPTEMBER 1992**
- **DATA EVALUATION AND TEST REPORT COMPLETED AND PROVIDED TO DFRF**  
**BY NOVEMBER 1992**
- **AUGMENTED TRANSPORT STANDARD PACKAGE PROVIDED TO JPL - MARCH 1993**

**STATUS REPORT - APRIL 20-22, 1993**

# **FY 1992 JSC/MSCL FIBER OPTIC POWER MAP PROGRAM**

## **PHASED APPROACH**

---

- **PHASE FOUR: FIBER OPTIC POWER MAP REVIEW**
- **SECOND NIST CERTIFICATION OF REFERENCE STANDARD ECPR**
- **VERIFY CERTIFICATION OF TRANSPORT STANDARDS**
- **REVIEW AND ANALYZE PARTICIPANT DATA**
- **DETERMINE IF FIBER OPTIC POWER SOURCES ARE SUITABLE AS TRANSPORT STANDARDS**
- **SURVEY OF ALL NASA CENTERS FOR INCREASED REQUIREMENTS AND INCREASED PARTICIPANTS**
- **DETERMINE NEED TO ENHANCE PARAMETERS COVERED BY FOMAP**
- **PROVIDE FINALIZE REPORT TO MCWG**
- **ARRANGE FOR JSC CONTINUATION OF FOMAP IF DETERMINED TO BE APPROPRIATE AND DESIRED**

**STATUS REPORT - APRIL 20-22, 1993**

# **FY 1992 JSC/MSCL FIBER OPTIC POWER MAP PROGRAM MAP PROGRAM COST**

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- **JSC MSCL CONTRIBUTION TO FOMAP STANDARDS COST:  
INITIAL: \$125,000  
ON-GOING: 1/4 MYE PER YEAR SINCE MAY 1, 1989**
- **NASA RTOP CONTRIBUTION TO FOMAP COSTS: \$75,000**

**STATUS REPORT - APRIL 20-22, 1993**

NASA JSC FIBER OPTIC MEASUREMENT ASSURANCE PROGRAM (FOMAP) STATUS  
UP TO MARCH 1993

NASA JSC FOMAP activity during the past year has centered around participant testing. The two original participants, Kennedy Space Center (KSC) and Dryden Flight Research Center (DFRC), have been provided the transport standard for their measurement and use and have supplied data to the FOMAP database.

Early this calendar year, the Jet Propulsion Laboratory (JPL) elected to become the third FOMAP participant. They will be given the normal transport standard power meter plus two fiber optic source instruments to augment the package. Preparations for shipment are essentially complete. The package will most probably be shipped to JPL during the month of March 1993. It is anticipated valuable data will be collected if the JPL metrology group can perform a series of tests and characterization measurements on these commercial sources.

The transport standard instruction manual has been revised and; hopefully, will be more useful to the program. If the data from the JPL tests of the sources are favorable, it is planned to include the sources with the transport standard on a routine basis in order to incorporate some measurement flexibility for the participants.

Following the JPL measurements, it is planned to perform a second round of measurements involving FOMAP PARTICIPANTS beginning mid-year 1993.

For our local customers we have developed a non-traceable capability for fiber optic cable length. Our artifact length standards were certified for length by the manufacturer. This was done to provide a service the customers needed and we felt we should develop. The overall JSC fiber optic capability is still only at the 850nm and 1300nm wavelengths. We have not received any inputs indicating that a calibration capability at other wavelengths is required at this time to satisfy any customer needs.



# **RTOP REPORTS**



# LEAK COMPARATOR SYSTEM

## KENNEDY SPACE CENTER STANDARDS LABORATORY

EG&G FLORIDA  
ZAN MILLER(407)867-4267

The leak comparator system was designed and built for the Kennedy Space Center Standards Laboratory under RTOP funding by the National Institute of Standards and Technology. Check standards were calibrated when the system was set up and our values came within the uncertainties given for the NIST values. The system is automatic, and designed to perform calibrations with minimal operator involvement.

The system is needed in order to provide temperature dependency information for permeation leaks and to differentiate between permeation and capillary leaks so they can be handled appropriately.

The primary standards which provide traceability to NIST are our standard leaks which are recalibrated periodically. The system is capable of calibrating leaks from  $10^{-6}$  to  $10^{-14}$  moles per second leak rates. Standards are currently available at  $10^{-7}$ ,  $10^{-8}$  and  $10^{-9}$  moles per second flow rates. The system compares the standard with an unknown in the same flow rate decade. Leaks in decades for which we have no standard can be calibrated by the closest standard with an added uncertainty of about 2 percent per decade difference to account for non-linearity in the mass spectrometer.

The system operates by comparing a NIST calibrated leak to an unknown leak. The comparison is done by establishing a steady flow through the system and using a mass spectrometer to measure the amount of helium present. Software was written to control the data acquisition and temperature and also the pressure in the leak reservoir, if needed.

The customer is provided with the leak type, the method of flow rate calculation, a table of values for different temperatures, and an uncertainty statement. Uncertainty consists of the sum of the uncertainty of the standard, the uncertainty of the temperature and pressure measurements and the random uncertainty as given by the analysis of residuals from fitting the data to the temperature versus leak rate curve. Uncertainties are reported at the three sigma level.

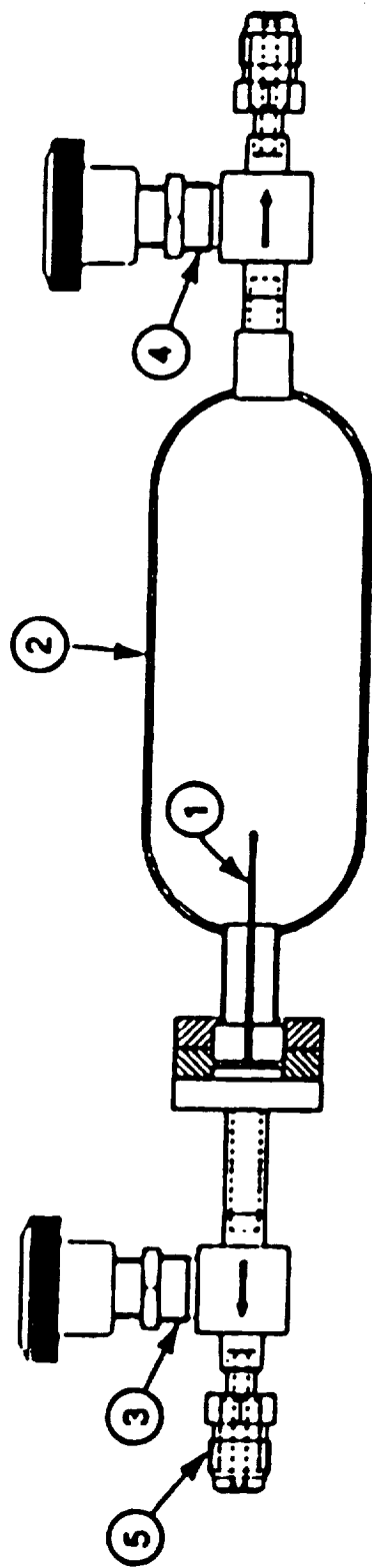
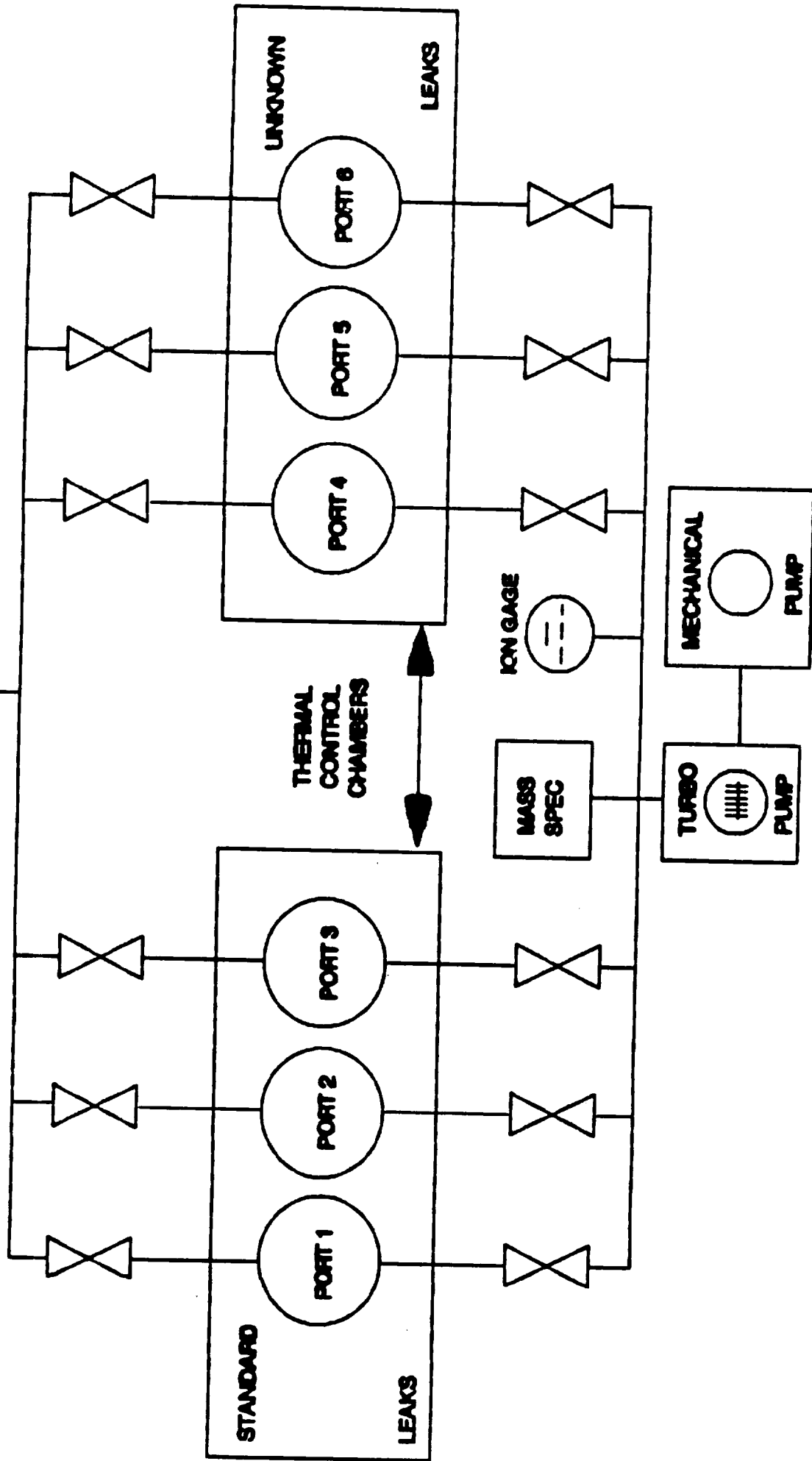
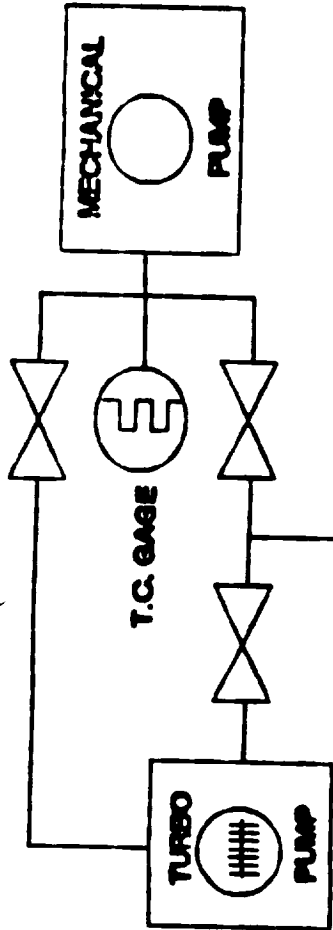


FIG. 1. Schematic diagram illustrating the major components of a leak. (1) leak element, (2) reservoir, (3) leak valve, (4) fill valve, (5) process connection.

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LEAK COMPARATOR  
KENNEDY SPACE CENTER  
STANDARDS LABORATORY



Data File:  
basal.ppn

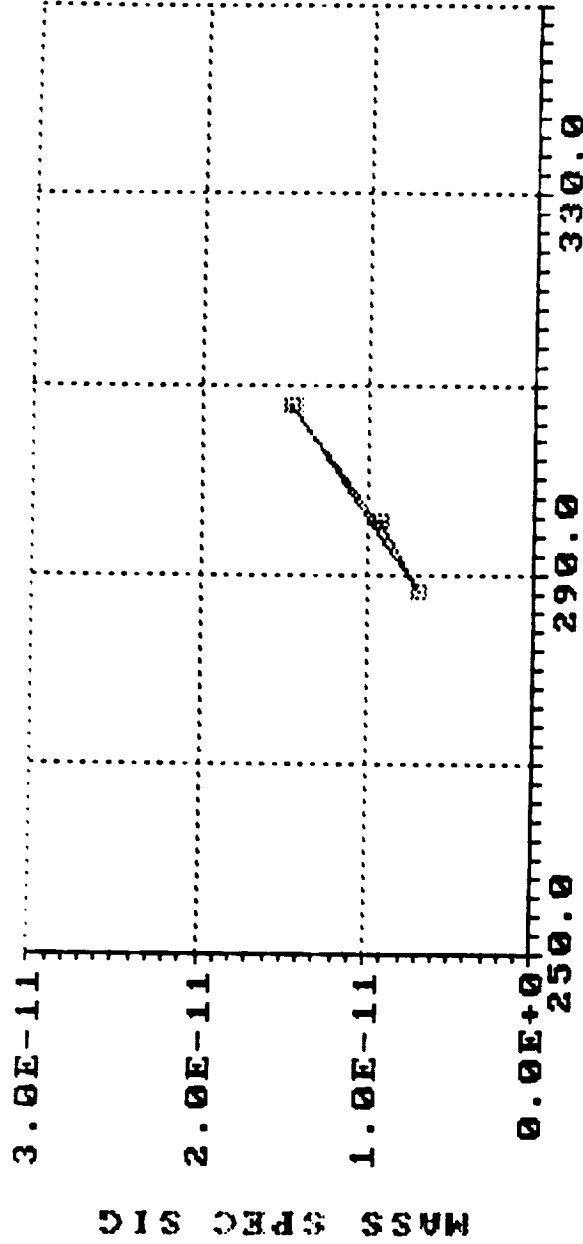
# LOG FIT

$Y =$   
 $9.3440E-10 * X ^ 0$   
 $-3.0478E+3 * X ^ 1$

Standard  
 Deviation  
 (Residuals) =  
 0.15%

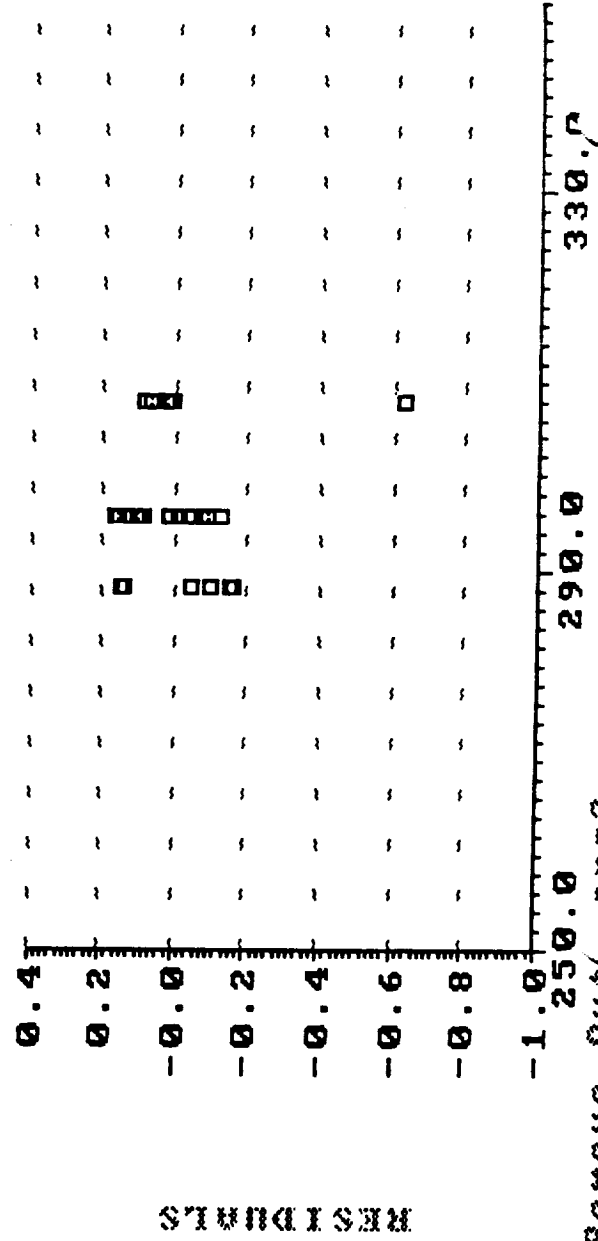
Standard Errors  
 of Coefficients  
 0.06 %  
 0.11 %

ORIGINAL DATA - SOLID, FITTED DATA - DOTTED



## LEAK TEMPERATURE

CURVE FIT ERROR ANALYSIS



Remove Outliers?

# REPORT OF TEST

Item Tested: Leak, Helium (Permeation)

The above identified item was tested with reference to standards maintained in the KSC Reference Standards Laboratory. The units maintained by the standards are directly traceable to the National Institute of Standards and Technology. The laboratory temperature during the test was 23.0 degrees Celsius.

The calibration was performed by comparing the leak rate of the test artifact with a NIST calibrated standard leak artifact using a quadrupole mass spectrometer. The standard leak was maintained near 23 degrees Celsius. The temperature dependence was generated by varying the temperature of the test leak from 15 to 35 degrees Celsius. The leak rate in moles per second was calculated using the equation for permeation leaks

$$\text{Leak Rate} = A \cdot T \cdot e^{-B/T}$$

The coefficients generated by this calibration are:

$$A = 1.3116e-10 \text{ mol/sK} \quad B = 3005 \text{ K}$$

## TEMPERATURE VS. LEAK RATE

		LEAK		RATE				LEAK		RATE	
°C	°F	scc/s	mol/s	°C	°F	scc/s	mol/s	°C	°F	scc/s	mol/s
1	33.8	1.50e-08	6.24e-13	26	78.8	4.09e-08	1.70e-12				
2	35.6	1.57e-08	6.52e-13	27	80.6	4.24e-08	1.77e-12				
3	37.4	1.63e-08	6.81e-13	28	82.4	4.40e-08	1.83e-12				
4	39.2	1.71e-08	7.11e-13	29	84.2	4.56e-08	1.90e-12				
5	41.0	1.78e-08	7.42e-13	30	86.0	4.73e-08	1.97e-12				

\* std cc/s refers to conditions of one atmosphere absolute pressure and 0 degrees Celsius. 1 std cc/s =  $4.46 \times 10^{-5}$  mol/s.

Under conditions of normal usage and storage at room temperature the leak rate of an artifact can be expected to decay. The decay rate of this artifact is a function of usage conditions and storage temperature and may vary.

To optimize the overall accuracy of this item it should be stored with any shut off valve open. A dust cover may be used to protect the port. The leak and the system on which it is used should be in temperature equilibrium with the environment, and should be pumped for three hours before use.

The estimate of the total uncertainty in the measured leak rate of this artifact during this calibration interval is  $\pm 6.78\%$ . This includes  $\pm 4.3\%$  uncertainty in the value of the standard,  $\pm 0.81\%$  random uncertainty in the flow rate and an uncertainty in temperature dependence over the range 0-50 degrees Celsius of  $\pm 1.67\%$ .





# **RTOP Report Metrology Reference Publication**

**16th ANNUAL NASA  
METROLOGY & CALIBRATION WORKSHOP  
Rockville, MD**

**22 April 1993**

**R.E. Martin**

**Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California, USA**

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## **Metrology Reference Publication**

- **Will Be NASA Reference Publication**
- **“Metrology — Calibration and Measurement Processes Guidelines”**
- **Approximately 250 pages**
- **Issues**
- **ISO/TAG4/WG3 “Guide to the Expression of Uncertainty in Measurement”**
  - **Adopt nomenclature/definitions?**
  - **Adopt guidelines for evaluating and expressing uncertainty? (Type A, Type B)**
- **No further Working Group review**

## **Metrology Reference Publication (cont'd)**

- **Final Work**
  - **Authors to review, comment, add examples**
  - **Revise document based on author/other inputs**
  - **Provide index**
  - **Perform Level 2 edit (check grammar, spelling, mechanical style, format, consistency, conciseness, and fluency) — revise accordingly**
  - **Provide camera-ready pages for printing**
  - **Print 300 comb-bound copies for initial distribution**
  - **Coordinate with NASA Scientific and Technical Information Program (STIP), Center for Aerospace Information (CASI), etc. for further unlimited distribution**

## **Metrology Reference Publication (cont'd)**

- **Cost**
  - **\$50K received at JPL**
- **Allocation**
  - **40% — Author review, rework**
  - **60% — In-house rework, edit, publish**
- **Schedule**
  - **Publish Final and distribute — end of CY93**

# MAP PUBLICATION

John P. Riley  
Kennedy Space Center

**16th Annual NASA Metrology and Calibration Workshop**

# MAP Publication

Lead Center: KSC

MCWG

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## ***Objective***

Provide guidelines on developing, documenting, implementing, and maintaining Measurement Assurance Programs within NASA

## ***Approach***

- Contract consultant to enhance current draft publication
- Review draft through Working Group
- Publish and distribute publication

## ***Status***

- Consultant draft completed September 1992
- Working Group review due April 1993

**MAP Publication**  
**Lead Center: KSC**

**MCWG**

---

***Benefits***

- Provides information to NASA Centers on operation of in-house and inter-Center MAPs
- Documents traceability to national standards for each MAP

***Funding (\$K)***

FY91	FY92	FY93	FY94
5	10	0	20

Measurement Assurance Program Publication

PERFORMING INSTALLATION: Kennedy Space Center

PRINCIPAL INVESTIGATOR: J. P. Riley    PHONE NO: (407) 867-4737

FUNDING: FY-94 - \$20K

**OBJECTIVE:**

Provide technical and administrative guidelines for developing, documenting, implementing, and maintaining Measurement Assurance Programs within and between NASA Field Installations.

**APPROACH:**

1. Contract consultant to enhance current draft publication.
2. Review draft through Working Group.
3. Publish and distribute publication.

**PAYOFFS:**

1. Provides information to NASA Centers on development, operation, and maintenance of in-house and inter-Center MAPs.
2. Documents traceability to national standards for each MAP.

**CUSTOMERS:**

1. All NASA calibration laboratories involved with MAPs.



# RTOP PROPOSALS





**Metrology and Calibration Workshop**

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# ***Transient Pressure Calibration***

**Presented by Troy Estes**

**April 22, 1993**



# Transient Pressure Calibration

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## Objectives

- Develop calibration system for transient pressures
  - Primary molecular standard
  - Shock tube reference standard
- Collaborate with NIST



# **Transient Pressure Calibration**

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## **Approach**

- Select calibration method
- Design and build calibration system
- Evaluate performance and accuracy of system
- Establish traceability



# Transient Pressure Calibration

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## Benefits

- State-of-the-art calibration system
- Improved accuracy (2 to 4 times better)
- Foundation for shock wave research



# **Transient Pressure Calibration**

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## **Customers**

- Explosion characterization
- Rocket engine performance
- Aerodynamics and wind tunnel instrumentation



# Transient Pressure Calibration

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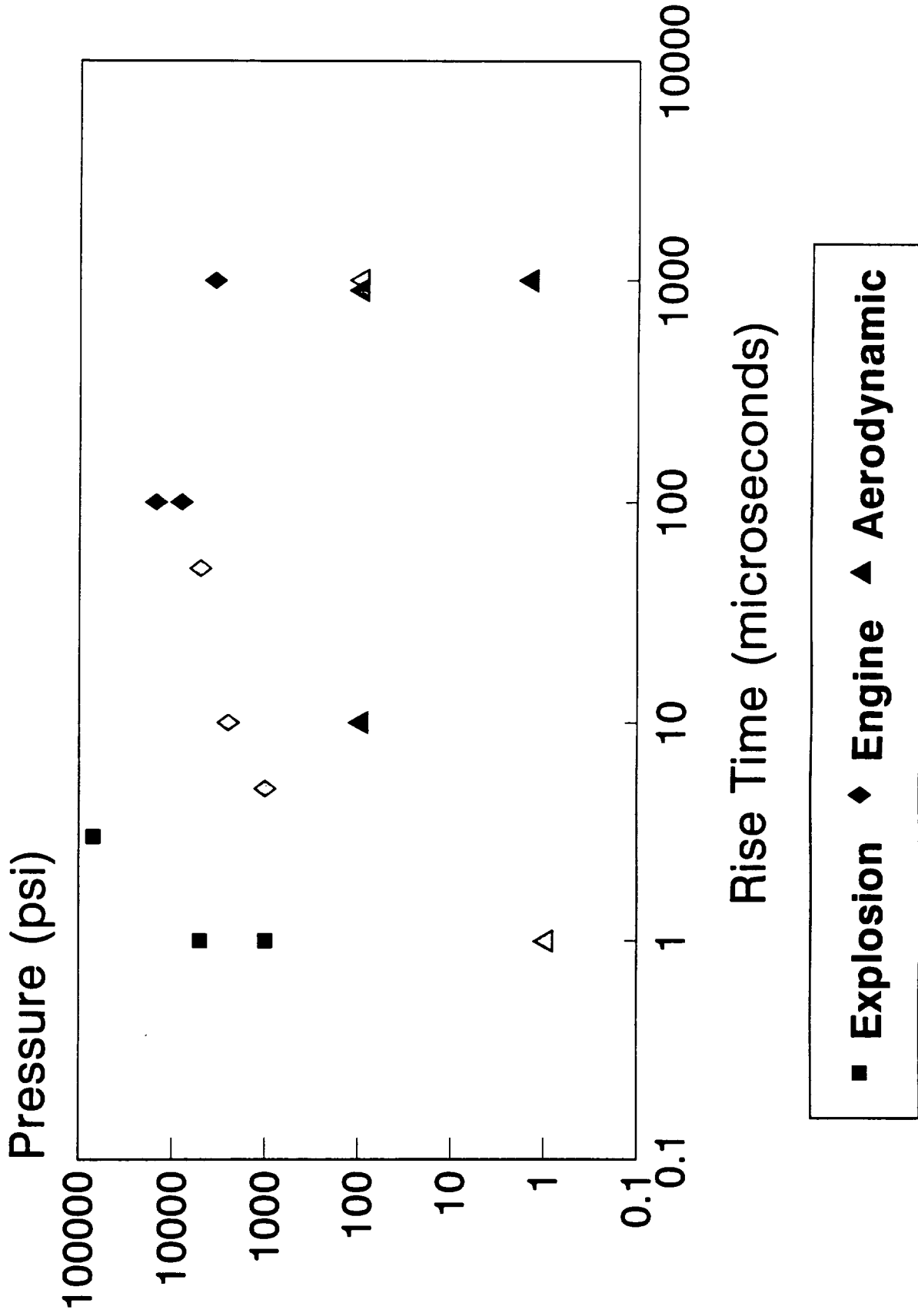
## Funding

FY94	\$120K	(\$40K NIST)
FY95	\$140K	(\$40K NIST)
FY96	\$ 90K	(\$40K NIST)



# Transient Pressure Requirements

## By Research Category





# VOLT MAP UPGRADE

Kristen J. Riley  
Kennedy Space Center

16th Annual NASA Metrology and Calibration Workshop

# **Voltage MAP Upgrade**

**Lead Center: KSC**

**MCWG**

---

## ***Objective***

Upgrade pivot laboratory transfer standards and provide automated traceability to field installations using 10 Volt solid state references

## ***Approach***

- Select and procure equipment
- Perform verification and acceptance testing
- Distribute equipment to field installations

# **Voltage M&P Upgrade**

**Lead Center: KSC**

**MCWG**

---

## ***Benefits***

- Delivers a sub-part-per-million, automated, Agency-wide volt maintenance program
- Reduces demand for NIST services with potential cost avoidance of \$13,000 per year for Agency
- Reduces cost of maintaining volt through automation with potential cost avoidance of \$84,000 per year for Agency

## ***Funding (\$K)***

FY94

75

Phase II of the Volt Measurement Assurance Program

PERFORMING INSTALLATION: Kennedy Space Center

PRINCIPAL INVESTIGATOR: K. J. Riley PHONE NO: (407) 867-4737

FUNDING: FY94 - \$75K

**OBJECTIVE:**

Upgrade pivot laboratory transfer standards and provide automated traceability to field installations using 10 volt solid state references.

**APPROACH:**

1. Select and procure equipment.
2. Perform verification and acceptance testing.
3. Distribute equipment to field installations.

**PAYOFFS:**

1. Delivers a sub parts per million, automated, Agency-wide volt maintenance program.
2. Reduces demand for NIST services.
3. Reduces cost of maintaining volt through automation.

**CUSTOMERS:**

1. NASA Metrology and Calibration Laboratories.
2. All programs requiring voltage measurements.

# PORTABLE J-VOLT STANDARD

Kristen J. Riley  
Kennedy Space Center

16th Annual NASA Metrology and Calibration Workshop

# Portable J-Volt Standard

Lead Center: KSC

## Objective

To develop and deliver a ruggedized self-contained portable J-volt system which can be shipped to participating field centers for absolute determination of each center's "volt" as maintained by solid state volt references.

## Approach

- Define NASA requirements
- Initiate a contract with the Department of Energy
- Complete system component design and development
- Complete system integration, software and procedure development



# Portable J-Volt Standard

## Lead Center: KSC

### Approach Continued

- Complete system training and deliver to KSC

### Benefits

- Reduced uncertainties from current VMAP
- Eliminates turnaround time
- Eliminates stability problems with SSVR transportation
- Test acceptance of high accuracy DVMS acquired by NASA Programs
- Support development testing of ultra-stable voltage sources for space applications

# Portable J-Volt Standard

Lead Center: KSC

## Funding (\$K)

FY94	FY95	FY96
90	100	100

Portable Josephson Junction Array Voltage Standard

PERFORMING INSTALLATION: Kennedy Space Center

PRINCIPAL INVESTIGATOR: K. J. Riley PHONE NO: (407) 867-4737

FUNDING: FY95 - \$90K, FY96 - 100K, FY97 - 100K

**OBJECTIVE:**

The technical objectives are to develop and deliver a ruggedized self-contained portable J-volt system which can be shipped to participating field centers for absolute determination of each center's "volt" as maintained by solid state volt references.

**APPROACH:**

This project would be a joint venture with the Department of Energy (Sandia National Laboratory), which is currently engaged in a J-Volt transport system development program.

1. Define NASA requirements.
2. Initiate a contract with the Department of Energy.
3. Complete system component design and development.
4. Complete system integration, software and procedure development.
5. Complete system training and deliver to KSC.

**PAYOFFS:**

1. Reduced uncertainties from current VMAP.
2. Eliminates turnaround time.
3. Eliminates stability problems with SSVR transportation.
4. Test acceptance of high accuracy DVMs acquired by NASA Programs.
5. Support development testing of ultra-stable voltage sources for space applications.

**CUSTOMERS:**

1. All NASA Metrology and Calibration Laboratories.
2. All programs requiring high accuracy voltage measurements.





# ACCELERATION MAP EXPANSION

16th ANNUAL NASA  
METROLOGY & CALIBRATION WORKSHOP  
Rockville, MD

22 April 1993

MIGUEL CEREZO

Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California, USA

## OBJECTIVE

To provide a dependable and cost effective method for participating centers to assess the quality of measurements made for shock transducer calibrations.

## Approach

- Procure shock calibration test system and transfer standard shock accelerometerometers.
- Configure and integrate with LALF calibration system.
- Expand AMAP calibration spectrum by incorporating shock measurements.

## Shock Calibration System

- **Transportation Shock**
  - Utilizes Drop Test Calibrator
  - Acceleration Level: 20 g to 10 Kg
  - Pulse Duration: 3 mS to 100  $\mu$ S
- **Pyrotechnic Shock**
  - Utilizes Hopkinson Bar Tester
  - Acceleration Level: 10 Kg to 100 Kg
  - Pulse Duration: 60  $\mu$ S to 160  $\mu$ S



## **Benefits**

- Provides direct NIST traceability at reduced cost to participants.
- Allows participants to quantitatively assess the measurement errors associated with their shock calibration systems and procedures.
- Provides evidence of measurement assurance for use in laboratory audits, certification and ISO9000 registration.
- Enables NASA to gain an understanding of the quality of shock calibrations being performed on an agency wide basis.

## Customer Base

- AMAP participants with shock calibration capabilities.
- NASA personnel interested in measurement and quality assurance.
- Other organizations
  - DOD, DOE, NIST, NCSL, etc.

## **Funding**

- **One Year Funding \$110K**
- **Shock calibration system and transfer standards**
  - System integration and testing
  - NIST certification
- **Expansion of AMAP**



**JOHNSON SPACE CENTER  
MEASUREMENT STANDARDS AND CALIBRATION LABORATORY  
RESEARCH AND TECHNOLOGY OBJECTIVE AND PLAN**

**RTOP PROPOSAL**

**CAPACITANCE MEASUREMENT ASSURANCE PROGRAM AT JSC  
FOR METROLOGY PROGRAMS AT ALL NASA CENTERS**

**PREPARED AND PRESENTED BY:  
R. D. SMITH  
SIMCO ELECTRONICS  
APRIL 19-22, 1993**

# JSC MSCL RTOP

## ESTABLISH CAPACITANCE MAP AT JSC

---

- BACKGROUND: 1989
  - JSC ASSIGNED RESPONSIBILITY AS PIVOT CENTER FOR NASA-WIDE CMAP
  - STUDY CONDUCTED: CURRENT STD. CAPACITORS NOT CAPABLE OF <5 PPM
  - JSC PROGRAM PUT ON HOLD UNTIL BETTER STANDARDS WERE AVAILABLE
- CURRENT SITUATION: NEW CAPACITANCE BRIDGE DEVELOPED AND MARKETING SUITABLE FOR USE AS TRANSFER MAP STANDARD
  - NIST SUCCESSFUL MAKING MEASUREMENTS OF 2 TO 3 PPM UNCERTAINTY AT 1000 AND 100 pF LEVELS USING NEW BRIDGE
- PRELIMINARY WORK PERFORMED
  - METROLOGY PROGRAMS AT ALL NASA CENTERS SURVEYED FOR INTEREST
  - POSITIVE ANSWERS RECEIVED FROM:
    - JET PROPULSION LABORATORY / KENNEDY SPACE CENTER
    - LANGLEY RESEARCH CENTER / MARSHALL SPACE FLIGHT CENTER
    - STENNIS SPACE CENTER / WALLOPS FLIGHT FACILITY
  - JSC PERFORMED CAPACITANCE MEASUREMENTS USING SIMILAR BRIDGE
    - = SUCCESSFUL IN MAKING MEASUREMENTS WITHIN 5 PPM UNCERTAINTY

GOAL: CONTINUOUS IMPROVEMENT

# JSC MSC L RTOP

## APPROACH TO ESTABLISHING CAPACITANCE MAP AT JSC

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### PHASE ONE

- OBTAIN CAPACITANCE BRIDGE AND OTHER REQUIRED HARDWARE  
COST: APPROXIMATELY \$12.2K

### PHASE TWO

- OBTAIN NIST CERTIFICATION OF CAPACITANCE BRIDGE  
COST: APPROXIMATELY \$9K
- TEST THE BRIDGE FOR SUITABILITY AS TRANSFER STANDARD
- PREPARE PROCEDURES FOR PERFORMING TRANSFER MEASUREMENTS  
COST: FY'94 \$5K

### PHASE THREE

- DETERMINE AND IDENTIFY PARTICIPATING NASA CENTERS
- ESTABLISH PARTICIPANT SCHEDULE
- SEND STANDARD TO FIRST PARTICIPANT  
COST: FY'95 \$10K AND FY'96 \$10K

**GOAL: CONTINUOUS IMPROVEMENT**

# JSC MSCL RTOP

## BENEFITS TO ESTABLISHING CAPACITANCE MAP AT JSC

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### BENEFITS TO NASA AGENCY

- \* REDUCTION IN COST OF MAINTAINING TRACEABILITY IN CAPACITANCE
  - \*\* COST OF NIST MAP PARTICIPATION OR COST OF NIST CALIBRATION OF BRIDGE: \$9K
  - \*\* WITH A MINIMUM OF SIX NASA CENTERS PARTICIPATING: SAVE \$54K
  - \*\* NET SAVINGS: \$45K
- \*\* COST OF DIRECT NIST CALIBRATION OF CAPACITORS: \$0.5K PER FREQUENCY 3 EACH CAPACITORS (1000, 100, AND 10pF) TYPICALLY CALIBRATED AT THREE FREQUENCIES: \$4.5K
- \*\* THE SIX NASA CENTERS PARTICIPATING WOULD SAVE \$27K
- \* REDUCTION OF POSSIBILITY OF DAMAGE TO STANDARDS DURING SHIPMENT
  - \*\* STANDARD BRIDGE WOULD REMAIN IN LABORATORY ENVIRONMENT; NOT EXPOSED TO DAMAGING SITUATIONS
  - \*\* STANDARD CAPACITORS SHIPPED TO NIST TEND TO CHANGE IN VALUE DUE TO SHIPPING AND HANDLING. SITUATION WOULD BE ELIMINATED
- \* RECEIVE BENEFITS OF NASA CAPACITANCE MAP PARTICIPATION WITHOUT ASSOCIATED COSTS
  - \*\* ESTABLISH AND IMPROVE MEASUREMENT SYSTEM UNCERTAINTY
    - MEASUREMENT SYSTEM INCLUDES; INSTRUMENTS, PERSONNEL, AND ENVIRONMENT
  - \*\* INTERCOMPARISON OF EQUAL FACILITIES, BUILDING CONFIDENCE
  - \*\* LEARNING NEW AND IMPROVED MEASUREMENT TECHNIQUES THROUGH INFORMATION INTERCHANGE

GOAL: CONTINUOUS IMPROVEMENT



The Johnson Space Center (JSC) Measurement Standards and Calibration Laboratory (MSCL) is proposing the establishment of a NASA Capacitance Measurement Assurance Program (CMAP) with the JSC MSCL as the pivot laboratory.

BACKGROUND - The JSC MSCL was selected to establish and conduct such a program in 1989.

It was determined through a detailed measurement process that the MSCL's standard capacitors were extremely temperature sensitive. That is, the temperature in the capacitor must be known at the time of capacitance measurements in order to determine the accuracy and uncertainty of the measurements. It was determined at that time that a Capacitance MAP was not feasible with the available equipment. Continuation of the development of a CMAP was placed on hold pending development of better standard capacitors or development of better means to measure capacitance.

PRESENT SITUATION - A new capacitance bridge has been developed and marketed. It has been tested for use as a transport standard by the National Institute of Standards and Technology (NIST). In fact, NIST has developed and implemented a CMAP using the new bridge process. NIST has been successful making measurements of 2 to 3 PPM uncertainty at 1000 and 100 pF levels with the new bridge.

With this in mind, all NASA center metrology programs were surveyed to determine their current needs for traceable capacitance measurements and to assess their desires to participate in a NASA CMAP. Metrology operations at the Jet Propulsion Laboratory, the Kennedy Space Center, the Langley Research Center, the Marshall Space Flight Center, the Stennis Space Center, and the Wallops Flight Facility all indicated a desire to participate and listed their specific measurement traceability requirements.

In consideration of this, the MSCL engineering staff commenced performing capacitance measurement using a bridge similar to the one NIST is using in their CMAP operation. The result of this has been the successful performance of capacitance measurements within 5 PPM uncertainty at 1000 and 100 pF levels.

APPROACH - The following approach will be utilized in developing and implementing the NASA CMAP:

Phase one will involve purchasing and testing the new Andeen Hagerling capacitance bridge and two "dummy" capacitors. The estimated cost of the required hardware is \$12.2K.

Phase two will involve; 1) obtaining a NIST certification of the bridge, 2) testing the bridge and "dummy" capacitors for suitability as transfer standards, and 3) preparing procedures for use in performing the transfer measurements if the acquired bridge and capacitors prove suitable as transfer standards. The cost involved with the completion of Phase two is estimated to be approximately \$5K during FY'94.

Phase three will involve; first, confirming the intention of those centers that initially indicated an interest and a need as still being interested in participation; second, establishing a participant schedule; and third, shipping the transfer package to the first participant. It is estimated that \$10K will be

required during FY'95 to adequately operate the CMAP. An additional \$10K will be required during FY'96 to continue the CMAP operation. From that point, FY'97 forward, the cost of the CMAP can be assumed by the JSC MSCL as part of the operation of the next contract.

BENEFITS TO NASA AGENCY - The benefits to the entire NASA Agency of establishing a CMAP will be as follows:

There will be a direct reduction in the cost of maintaining traceability of all capacitance measurements made at any of the participating centers. The cost of a NIST CMAP participation is approximately \$9K. The cost of a direct NIST certification of a capacitance bridge suitable as a reference standard is \$9K. With a minimum of six NASA centers participating the minimum gross savings would be \$54K. Considering that one center will still be required to obtain NIST certification of the transport standard bridge, a net savings of \$45K will be realized through the use of this program.

Also, if each NASA center obtained their capacitance traceability through the practice of sending standard capacitors to NIST for direct certification the cost would be \$0.5K per frequency. Typically three capacitors (1000, 100, and 10 pF) are calibrated at three frequencies. The combined cost is \$4.5K per center or \$27K for all six participating centers. This total cost would be saved if the CMAP is implemented.

With the implementation of a CMAP, the possibility of damage caused by transporting each center's capacitance standard, whether bridge or standard capacitor, to NIST periodically for certification would be eliminated. Standard capacitors tend to change in value when they are shipped back and forth to NIST; you never are sure of the data you have been provided.

Establishing a NASA CMAP will allow for the reception, by five of the six centers identified as interested, of a direct traceability of their capacitance measurements without the associated costs. Only one center would have to pay the cost of a NIST CMAP participation and all centers would reap the benefits.

With an active NASA CMAP, each center's total capacitance measurement system would receive certification; the instrumentation, the personnel, and the laboratory environment would be tested and certified during the MAP process. The MAP process, by its very nature, opens all participants to confidence building through intercomparison of measurement system capabilities; a learning process through information interchange and technique sharing.

SUMMARY - Establishing a NASA CMAP is just as important as establishing a DC Volt MAP, a Resistance MAP, and an acceleration MAP. The benefits will be just as valid and important. The cost, minimal at best, will be a wise and fruitful investment. \$46.2K invested over a three year period, yielding \$45K each year starting with the first year, is a conservative estimate of the cost of the program and the associated savings to the NASA budget.

# **Flight Qualified Solid State Voltage Reference Module**

**16th ANNUAL NASA  
METROLOGY & CALIBRATION WORKSHOP  
Rockville, MD**

**22 April 1993**

**S.M.Bednarczyk**

**Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California, USA**

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## Introduction

- What is it?
- Why do we need it ?
- Why should it be developed now?
- NMWG Role

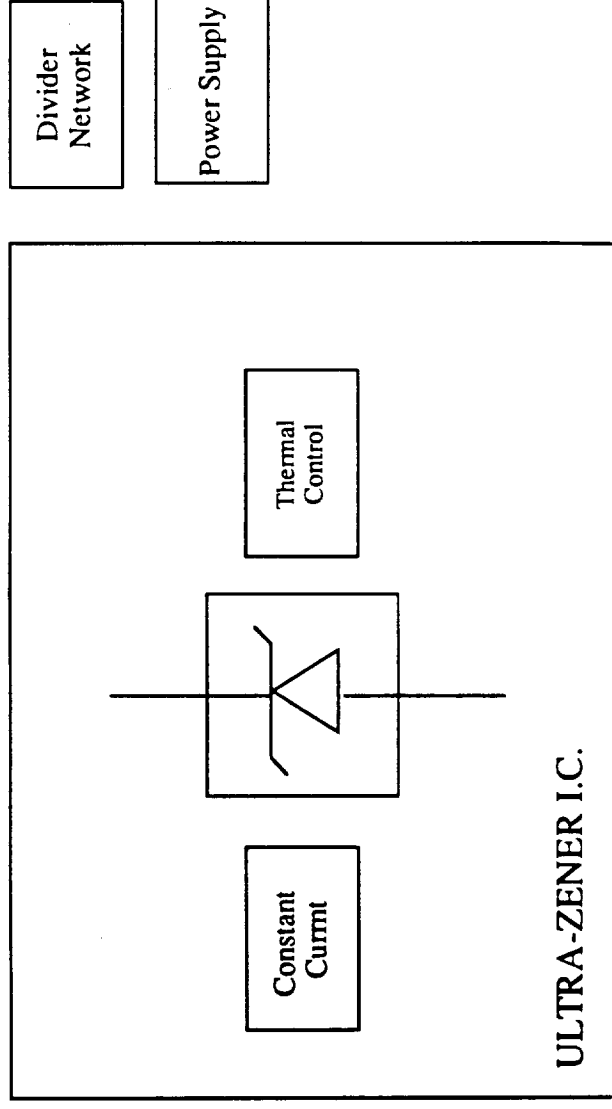
## **OBJECTIVE**

- To Provide a solid state voltage module suitable for space applications that require traceable voltage measurements.

## **Approach**

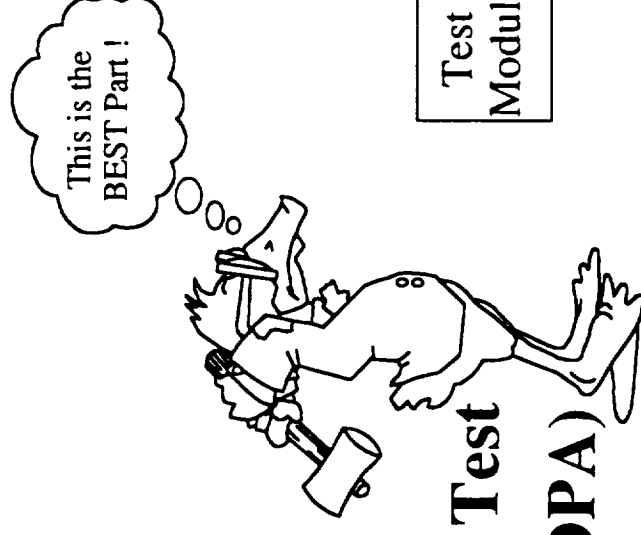
- **Survey available voltage standards for stability, appropriate voltage level and qualification level**
- **Select and test best available standard**
- **Design and fabricate module**
- **Test voltage module under environmental conditions**

## Design & Fabricate Test Module



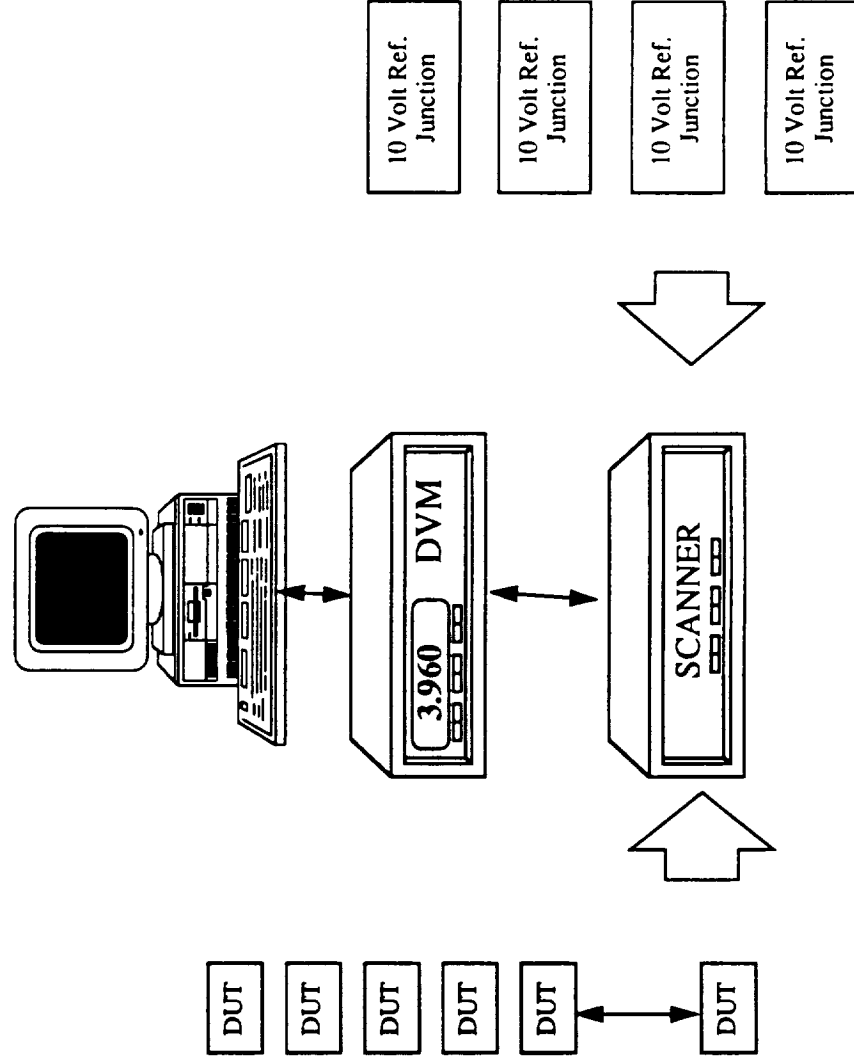
## Test the Module under use Environment

- Particle induced noise (PIND)
- Temperature Cycling
- Electrical Characterization
- Total Radiation Radiation Dose Test
- Destructive Physical Analysis (DPA)





## Typical Test Configuration



*Ultra-Zener Voltage Standard 7*

## RTOP Deliverables

- Document Design and test data and publish for Technology Transfer

## **Benefits**

- **A proven design for a stable voltage reference module for incorporation in space subsystems, flight experiments and instruments**
- **Improved data reliability by traceability to international standards**
- **Increased confidence for *in-situ* data analysis**
- **Universal design - “*One size fits all*”**

## Customer Base

- SSF Resource
- Experimenters
- Instruments
- Life Support Systems Check
- Other space-based platforms

## **Funding**

- **Two Year Project \$100K/Yr**
- **First Year**
  - **Survey**
  - **Evaluate & select device**
  - **Design & fabricate voltage module**
- **Second Year**
  - **Test & evaluate module**
  - **Document design & test Data**



# MASS MAP

John P. Riley  
Kennedy Space Center

16th Annual NASA Metrology and Calibration Workshop

# **Mass MAP**

**Lead Center: KSC**

**MCWG**

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## ***Objective***

Use proven measurement assurance methods to provide a uniform basis for mass measurements traceable to NIST

## ***Approach***

- Procure mass standards and obtain NIST calibration
- Develop data reduction software and procedures
- Initiate MAP and report results



***Benefits***

- Provides traceability at required accuracies (6 parts per million for Shuttle pressure and force measurements)
- Reduces demand for NIST services (\$6500 annual cost savings)
- Reduces NIST turnaround time from 3 months to 1 month

***Funding (\$K)***

FY97

10

**Mass Measurement Assurance Program**

**PERFORMING INSTALLATION:** Kennedy Space Center

**PRINCIPAL INVESTIGATOR:** J. P. Riley    **PHONE NO:** (407) 867-4737

**FUNDING:** FY94 - \$10K

**OBJECTIVE:**

Use proven measurement assurance methods to provide a uniform basis for mass measurements traceable to the National Institute of Standards and Technology (NIST).

**APPROACH:**

1. Procure mass standards and obtain NIST calibration.
2. Develop data reduction software and procedures.
3. Initiate MAP and report results.

**PAYOFFS:**

1. Provides traceability at required accuracies (6 parts per million for Shuttle pressure measurements).
2. Reduces demand for NIST services (\$6500 annual cost savings).
3. Reduces NIST turnaround time from 3 months to 1 month.

**CUSTOMERS:**

1. All calibration laboratories providing mass calibrations.
2. Shuttle program.

**JOHNSON SPACE CENTER  
MEASUREMENT STANDARDS AND CALIBRATION LABORATORY  
RESEARCH AND TECHNOLOGY OBJECTIVE AND PLAN**

**RTOP PROPOSAL**

**ESTABLISH JOSEPHSON JUNCTION VOLTAGE STANDARD AT JSC**

**PREPARED AND PRESENTED BY:**

**W. T. MCPETERS  
SIMCO ELECTRONICS  
APRIL 19-22, 1993**

# **JSC MSCL RTOP**

## **ESTABLISH JOSEPHSON JUNCTION**

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- ESTABLISH CAPABILITY TO MEET INCREASING JSC MSCL CUSTOMER ACCURACY REQUIREMENTS
- ESTABLISH ABSOLUTE VOLTAGE STANDARD FOR TOTAL NASA AGENCY
- ESTABLISH ABSOLUTE REFERENCE FOR MCWG 10 VOLT MAP PIVOT CENTERS
- ESTABLISH CAPABILITY TO PROVIDE ABSOLUTE LINEARITY CALIBRATIONS FROM - 12 TO + 12 VOLTS DC
- ESTABLISH CAPABILITY TO MINIMIZE TURNAROUND ASSOCIATED WITH USING NIST AS ABSOLUTE REFERENCE
- REDUCE COST ASSOCIATED WITH MAINTAINING REFERENCE TO NATIONAL STANDARDS
- SHARE KNOWLEDGE AND EXPERIENCE GAINED THROUGH INSTALLATION AND OPERATION OF ABSOLUTE STANDARD

**GOAL: CONTINUOUS IMPROVEMENT**

# JSC MSCL RTOP

## ESTABLISH JOSEPHSON JUNCTION

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- MEET INCREASING CUSTOMER REQUIREMENTS
- ORGANIZATIONS REQUIRING MORE ACCURATE SERVICE  
JSC SR&QA INSTITUTIONAL SAFETY AND QUALITY DIVISION
  - \* JSC MEASUREMENT STANDARDS AND CALIBRATION LABORATORY  
JSC ENGINEERING DIRECTORATE
  - \* JSC NAVIGATION CONTROL AND AERONAUTICS DIVISION
  - \* JSC CREW AND THERMAL SYSTEMS DIVISION
- NASA MCWG 10 VOLT DC MEASUREMENT ASSURANCE PROGRAM PIVOT CENTERS
  - \* KENNEDY SPACE CENTER (KSC) METROLOGY LABORATORY
  - \* AMES RESEARCH CENTER (ARC) METROLOGY LABORATORY
- INSTRUMENTS REQUIRING MORE ACCURATE SERVICE  
STATE-OF-THE-ART PRECISION MULTIMETERS (8 AND 1/2 DIGITS)
  - \* SEVEN IN USE AT JSC WITH THREE MORE ON ORDER  
NASA MCWG 10 VOLTS DC MAP STANDARDS
  - \* MINIMUM OF TWO: 1 AT KSC AND 1 AT ARC
- FUNCTIONS REQUIRING MORE ACCURATE SERVICE  
ABSOLUTE DC VOLTAGE MEASUREMENT  
ABSOLUTE LINEARITY MEASUREMENT FROM - 12 TO + 12 V DC

**GOAL: CONTINUOUS IMPROVEMENT**

# JSC MSCL RTOP

## ESTABLISH JOSEPHSON JUNCTION

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- JSC MSCL WOULD OPERATE AS THE DC VOLTAGE REFERENCE SOURCE FOR ALL NASA CENTER'S METROLOGY PROGRAMS
  - \* NIST WOULD NO LONGER BE REQUIRED TO FURNISH ABSOLUTE REFERENCE
  - \* REFERENCE SUPPLIED BY JSC MSCL WOULD BE AS ACCURATE AS NIST SUPPLIED REFERENCE
  - \* TURNAROUND WOULD BE MUCH FASTER THAN NIST CAN PROVIDE SINCE THE ONLY USERS WOULD BE NASA FIELD CENTER METROLOGY PROGRAMS
- THE COST TO USERS WOULD ONLY BE SHIPPING CHARGES
  - \* NIST CHARGES OF \$3K (MAP PARTICIPATION) WOULD BE SAVED FOR EACH SERVICE AVOIDED
- NASA CENTER DC VOLTAGE STANDARDS WOULD BE EVALUATED MORE THOROUGHLY SINCE TIME WOULD BE AVAILABLE AT NO COST TO USER
  - \* WOULD GAIN VALUABLE KNOWLEDGE OF EACH STANDARD
  - \* EACH CENTER WOULD HAVE BETTER INSIGHT AS TO WHICH STANDARDS ARE BEST FOR THEIR INDIVIDUAL PROGRAMS

GOAL CONTINUOUS IMPROVEMENT

JOHNSON SPACE CENTER MEASUREMENT STANDARDS AND CALIBRATION LABORATORY  
RESEARCH AND TECHNOLOGY OBJECTIVE PLAN PROPOSAL

ESTABLISH JOSEPHSON JUNCTION VOLTAGE STANDARD FACILITY AT JSC

REQUIREMENTS FOR AND JUSTIFICATION OF ESTABLISHING THE JOSEPHSON  
JUNCTION VOLTAGE STANDARD CAPABILITY AT JSC

The following points are offered as rationale for establishing a Josephson "J" Junction absolute voltage standard capability at the JSC Measurement Standards and Calibration Laboratory.

1. Customers of the JSC Measurement Standards and Calibration Laboratory (MSCL) are purchasing the latest and most accurate measurement instrumentation available. It has become difficult, if not impossible, to maintain the NASA required 4:1 calibration accuracy ratio while calibrating this increasing number of instruments. The Josephson Junction Voltage Standard would permit adequate accuracy ratios when calibrating our standards and our customers' instruments.

JSC users include: JSC SR&QA Institutional Safety and Quality Division, JSC MSCL, JSC Engineering Directorate, JSC Navigation Control and Aeronautics Division, JSC Crew and Thermal Systems Division, plus additional new requirements every month.

Additionally, with the "J" Junction, JSC would be in a position to:

- a. Furnish all NASA Agency installations access to an absolute voltage standard between -12 and +12 Volts at an uncertainty of less than 0.1 ppm. This could be accomplished as an extension of the NASA Metrology and Calibration Working Group (MCWG) Measurement Assurance Program (MAP) for Direct Voltage. With the "J" Junction Voltage Standard and the MCWG 10 Volt MAP, a test instrument with absolute voltage calibration could be transferred to the NASA Direct Voltage Pivot Laboratories as a Voltage Standard. The current NASA Agency pivot laboratories are the Kennedy Space Center Metrology operation and the Ames Research Center Metrology operation
- b. Furnish absolute linearity calibrations from -12 to +12 Volts to any NASA field installation requiring this service.
- c. Minimize excessive turnaround times and the expense of NIST testing in obtaining traceability to national standards for all NASA Agency installations participating in the MCWG MAP.

2. Establishment of a "J" Junction facility at JSC would provide the following benefits to the total NASA Agency.

- a. Our dependence on external NIST certification for Direct Voltage would, for all practical purposes, be eliminated.
- b. JSC would have the capability to test many instruments more completely to ensure the outstanding linearity specifications of some newer DVMs; which would, in turn, increase our customer's confidence in this measurement parameter and; concurrently, in the total NASA metrology community.

- c. This defined Direct Voltage Reference would be available to the entire NASA community, allowing further cost savings, since the Direct Voltage Pivot Centers would no longer be dependent on NIST as their only reference source.
  - d. If other NASA Centers find they require a "J" Junction at a later date, the first hand experience gained from the JSC "J" Junction implementation and operation would be readily available to all interested NASA installations.
3. The first \$30K proposed in the RTOP will be used to:
- a. Study and evaluate the cost effectiveness to the NASA Agency for one center to be the absolute reference source for all other centers for absolute D.C. voltage, and
  - b. Perform a study to determine the value-added component, if any, in implementing an autonomous agency program. And, research the available market for the hardware and software required to establish the stated capability.

If the results of a and b immediately above are positive, the \$125K requested in the second FY of this program would be used to purchase all necessary hardware and software required to establish the stated capability.



## **MEASUREMENT PROCESS ENGINEERING TRAINING**

- **PURPOSE:** Provide a training course available to the Centers that teaches the concepts, methodology, and techniques of “Metrology — Calibration and Measurement Processes Guidelines” reference publication.
- **AUDIENCE:** Systems engineers, research engineers and scientists, measurements process and calibration systems designers, test engineers.
- **CUSTOMERS:** All Centers and program offices.

## **MEASUREMENT PROCESS ENGINEERING TRAINING**

- **APPROACH:**

- 1) Develop course and training material**
- 2) Preview and tune course at a selected Center.**
- 3) Video tape course presentation and prepare final set of training material.**
- 4) Make available course to Centers for presentation**

## **MEASUREMENT PROCESS ENGINEERING TRAINING**

- **COURSE CONTENT: (Met ref. publication)**
- **Measurement requirement specification and analysis.**
- **Measurement systems design**
- **Evaluation of measurement system error**
- **Constructing error models and estimating measurement uncertainty and measurement reliability.**
- **Establishing measurement traceability .**

## **MEASUREMENT PROCESS ENGINEERING TRAINING**

- **COURSE FORMAT:**
  - Three day workshop
  - Max of 25 in class
  - Classroom instructor , video tapes, and workbook
- **SCHEDULE:** Nine month for start
- **COST:** ~\$100K



**Metrology and Calibration Workshop**

# ***Microwave Measurement Assurance Program***

**Presented by Troy Estes**

**April 22, 1993**



# Microwave MAP

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## Objectives

- Develop MAP for microwave disciplines:
  - Attenuation
  - Phase
  - Rise time
- Provide traceability to national standards



# **Microwave MAP**

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## **Approach**

- **Establish WSTF as hub**
  - Select transport standards
  - Develop procedures and logistics
  - Obtain NIST calibration
- **Conduct round robin**
- **Finalize MAP procedures**
- **Provide on-going traceability using SPC**



## Microwave MAP

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### Customers

- Calibration laboratories conducting microwave frequency calibrations
- GSFC satellite ground terminals





## **Microwave MAP**

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### **Status**

- Standards due from NIST in 1 week
- Logistics/procedures in final preparation
- Round robin scheduled for May-July 1993
- Interesting "side-effects" discovered



## Quantum Electrical Standards

Intrinsic metrological standards required for space applications.

Principals: A. F. Clark, M. E. Cage, R. L. Steiner, and E. R. Williams

Introduction: This proposal is to develop the intrinsic standards presently used at NIST so they can better serve NASA's calibration needs. Included here are several research areas in which we believe an increase in our program would be of benefit to NASA. NASA's input as to which areas should be developed fastest is a key part of this proposal. The quantum Hall resistance is a good example. This intrinsic resistance standard is routinely used in primary laboratories to obtain better than 0.01-ppm accuracy. A major practical complication comes from the temperatures presently required to ensure such accuracy (~ 250 mK). Increased research on device fabrication should lead to higher operating temperatures as well as better availability of the present samples.

Technical Background: As flight durations increase and demand for more accurate measurements increase, the need for electric standards based on intrinsic standards rather than calibrated artifacts becomes imperative. At present the Josephson arrays and the quantum Hall resistors form the basis for the electric units maintained in terms of fundamental constants of nature. The Fundamental Electrical Measurements (FEM) group of the Electricity Division has the responsibility to realize these units, in order to start the calibration chain. Not only must we realize these units for calibration purposes, but also we must apply these calibrations to complex experiments that require the highest possible accuracy. This proposal outlines several areas in which we have experience that will be useful to NASA. Funding for the purpose of improving quantum standards would be directed according to the specific NASA needs, which will likely change rapidly as intrinsic standards form the basis of NASA's calibration program. One specific example should help give specific definition to this proposal.

- 3 NMR current source: In order to measure the SI value of the Josephson volt (i.e., the value of  $2e/h$ ) we are measuring the SI watt. In this laboratory we need current and voltage sources that are stable at about the 0.01 ppm level. A Josephson array has sufficient accuracy to meet our need, but it is difficult to connect it directly to an experiment that is difficult to shield against rf interference and it is difficult to operate unattended for 24 hours a day. To provide a better reference we designed a nuclear magnetic resonance-based current-voltage source. We introduced a new solenoid geometry for producing magnetic fields. This geometry reduces the problem of background noise and drifts due to thermal noise. It also allows the use of magnetic materials that were not allowed or caused problems in earlier nuclear magnetic resonance (NMR) based current sources. This current standard shows that our new NMR scheme

## RESEARCH PROPOSAL TOPICS FOR NASA

19 April 1993

has produced a current-voltage source that is comparable to the best zener diode references. This present current source already has less drift than commonly used current sources based on mercury battery references. Unlike zeners the NMR current can be turned off, then on, and retain its high accuracy. At NASA such a rugged current source could prove very useful. At the same time that we make a standard we could also measure the vector component of the ambient magnetic field. (Many NMR systems only measure the total magnitude of the field.) Exploring further this new current source would be beneficial to NASA. Listed below are several other areas that the FEM staff feel would be beneficial to NASA.

- 2 Quantized Hall Effect Resistance Standard: Develop a prototype quantum Hall effect (QHE) resistance standard for use in NASA's primary standards laboratories having a precision and absolute accuracy of 0.1 parts-per-million (ppm). The standard will be absolute (i.e., give a value in SI units) and be capable of monitoring resistance standards at the 10 k $\Omega$  level. Investigate the use of quantized Hall resistors as an absolute ac resistance standard for frequencies between 20 Hz and 10 kHz. This project also addresses the effect of sample processing parameters on the performance of quantized Hall devices, with the aim of producing standards that operate at temperatures above 1.2 K, thus eliminating the need for expensive low temperature refrigerators.

Single Electron Tunneling: A new quantum phenomenon based on the charging effects caused by the discrete value of the electron is being studied for metrological applications. Recent progress in nanofabrication has enabled the observation of Coulomb blockade effects in metallic and semiconducting systems. Since the conductance of these devices is determined by sequential single electron tunneling (SET), they hold great promise for metrological applications such as quantum noise limited electrometers and current sources. We propose to fabricate quantum wire devices using the focused ion beam at the NNF and by using scanning tunneling microscope lithography being developed in the Semiconductor Division at NIST. These quantum devices can be used to vary both the Fermi energy (i.e., the electron number) and the tunneling barrier height in the narrow channel in these structures. Si-MOS technology could be used to fabricate well-shielded capacitors monolithically integrated with the SET devices. We have recently proposed a novel precision measurement of  $\alpha$  and  $e$  utilizing SET devices to count electrons on a capacitor. We thus plan to study the physics of Coulomb blockade while developing a competence in the application of single electron tunneling to electrical metrology. We have devised a new scheme for measuring capacitors that is independent of frequency. This scheme will help link our calculable capacitor and quantum Hall programs with the new nanostructure program.

19 April 1993

① Josephson Array AC Waveforms: To research the generation of mV-level, precisely generated AC signals at frequencies above 1 Hz to over 1 MHz using frequency modulation (FM) techniques on a Josephson-junction array. This research will expand on the proven ability to generate 1000 Hz and 400 Hz AC signals with 300  $\mu$ V amplitude using 25 MHz FM at 85 GHz, and will explore the possible methods of, or limits to, generating frequencies at 100 kHz or higher. The accuracy of these AC waveforms is comparable to that of the DC Josephson standard and would provide improved calibration capabilities in areas where Josephson AC signals can be generated.

✓ Josephson Array Volt System Diagnostics: The daily operation of a Josephson array volt system is often complicated by both common problems arising directly from failures of the system's instruments to subtle interactions between two or more system components. Although operation of a remote site array system can be well automated, the electronic expertise needed in maintenance and repair of such a system requires backgrounds in array physics, ultra-sensitive DC voltage metrology, high frequency noise electronics, and microwave engineering. We propose to systematize a maintenance program with a hierarchical diagnostic catalog of problems experienced in regular array operations. This would benefit system operators who need to perform on-site maintenance, and would help in diagnosing problems in a remotely operated system.

Half-integral Voltage Steps in the Josephson Effect: Half-integral voltage steps are seen in both conventional Josephson array voltage standards and Josephson junctions fabricated from the new high critical temperature superconductors, not necessarily caused by the same phenomenon. The former creates uncertainty in calibrations and the latter are an intriguing effect that may impact the ultimate application of the high  $T_c$  materials for standards. The conditions for half-integral steps in the array standards will be documented, and methods to avoid their occurrence in conventional arrays will be established. A model already developed may explain the half-integral steps in the complex structure of the high  $T_c$  superconducting junctions. This model will be applied to the conventional arrays as well as to generate the understanding needed to use the high  $T_c$  materials for space applications.

Dual Josephson Array Applications: The series array of Josephson junctions that is used for our present voltage standard generates a precise 1 to 10 volts. We have compared completely independent array systems to an accuracy of 1 part in  $10^{10}$  at room temperature, but individual junctions in the same cryostat have been shown equivalent to parts in  $10^{18}$ . This leaves a wide range of potential measurement accuracy to be explored for precision comparisons of voltage or microwave frequencies. We have a dual array cryostat to compare two individual series arrays both with the same and slightly different microwave frequencies to demonstrate possible applications of this system. Such applications as detecting slight microwave differences from very small length changes to very small voltage differences will be studied.

## RESEARCH PROPOSAL TOPICS FOR NASA

19 April 1993

Funding request: This will be a three-year effort. Our funding request, per year, is given below. Note that these projects will be heavily supported by NIST internal funding as well. Also note that the specific deliverables to NASA are to be selected from the topic options presented in this proposal through discussions between NASA and NIST staff.

Labor	Other Objects	WY's
\$ 300k	\$ 50k	1.5

**NIST Electricity and Electromagnetic Technology Divisions  
Research Proposal to NASA**

**AC Measurements at the Quantum Limits of Sensitivity**

**Principals:** J. R. Kinard, T. E. Lipe, D. G. McDonald, & J. E. Sauvageau

**Summary:** This proposal is to develop the next generation of ac-dc difference standards relating ac voltage and current (fundamental and highly important to industry) to dc primary standards using a super-conducting environment to investigate the underlying physics in thermal transfer standards at the sub-ppm level. The two limiting factors in converter performance — thermoelectric effects in resistive structures and sensing of small temperature changes — will be addressed by the operation of transfer standards and studies of materials performance at cryogenic temperatures and the use of a kinetic inductance temperature sensor, respectively. These will be required to calibrate new thin-film multijunction thermal converters (FMJTCs) capable of performance at the 1 - 5 ppm level or better over the frequency range from 10 Hz to 10 MHz. The new FMJTCs will be commercially available and affordable as a result of a cooperative research and development agreement between NIST and Ballantine Laboratories over the past two years.

**Technical Background and Strategy:** The Electricity and Semiconductor Electronics Divisions are well along in a joint effort with Ballantine Laboratories to develop and commercialize FMJTCs. These devices have the potential to match the performance of NIST primary standards in the audio frequency range and have the advantage of extending primary standard performance levels to frequencies of tens of MHz, affording a large improvement in accuracy and reliability over standards presently available. These converters will be commercially produced and be affordable for general laboratory use throughout the measurement community. Versions of them have been proposed for inclusion in multimeters; if successful this would lead to ac voltage specifications nearly as good as those for dc voltage measurements.

A new generation of primary standards will be needed at NIST, and perhaps in NASA labs, to ensure that FMJTC-based standards and instruments can be supported at their limits of performance. This is needed for NIST to guarantee that the instrumentation industry's ability to develop new devices and instrumentation is not limited by the level of NIST's calibration services. It will be needed at NASA to evaluate new instrumentation with improved ac measurement specifications and to provide calibration support for such instrumentation. This proposal represents a joint effort between the Electricity and Electromagnetic Technology Divisions to produce such new standards.

The approach of applying superconductivity to such standards takes advantage of the fact that superconducting devices, such as SQUID's — for use as low-level detectors — and kinetic inductance thermometers — to monitor the temperature rise in heaters — perform at the quantum limits of sensitivity; i.e., there is simply no more sensitive means of making such measurements. Hence, the potential for some very interesting research in thermoelectric effects, and the possibility of developing the "ultimate" standards for ac-dc difference are both very high. The need for research on thermoelectric effects is fundamental. These effects in the heater ultimately limit the frequency response of any converter. They may be significantly reduced or more predictable at very low temperatures. The best existing converters have ac-dc differences on the order of 0.2 - 0.5 ppm over a limited frequency range. Serious improvements to this level of performance require a better understanding of thermoelectric effects than is presently available.

In parallel to this research, the development of improved standards will proceed along three lines. First, SQUID's will be used as output detectors for operating FMJTC's at liquid nitrogen temperatures in order to investigate noise limitations in those devices. New film thermal converter configurations will be designed to permit examination of the thermal characteristics of heaters and monitoring structures in order to improve the performance of future designs. This approach will also be used to re-evaluate existing primary standards to verify and refine the measurement uncertainties associated with them.

Second, new and improved schemes for the construction of cryogenic thermal converter structures and to monitor heater temperature will be developed and tested. Most important of these will be that of adopting the superconducting kinetic inductance techniques developed by the Cryoelectronic Metrology Group for IR power measurements to film heater designs to produce an experimental kinetic inductance converter (KITC) to run at liquid He temperatures. New superconducting shields and transmission lines will be studied. Other possibilities involve optimizing thermopile materials for use in liquid nitrogen. An investigation of possible use of high-temperature superconductors to assess the feasibility of operating a version of superconducting kinetic inductance device at higher temperatures, perhaps even at liquid nitrogen temperatures, may be undertaken.

Finally, custom FMJTC's and KITC's designed specially to permit analytical modelling of their behavior at about 8 K will be fabricated and their relative performance compared with that predicted by the models. Such designs will take into account the difficulties of defining the measurement plane (important at higher frequencies) and dealing with the large and variable thermal emf's experienced in circuits in very large temperature gradients.

**Expectations:** The near-term goal of this activity is a new generation of standards of ac-dc difference that have predictable performance (uncertainties) at the  $< 0.1$ -ppm level in the audio-frequency range and 1 ppm at frequencies up to a megahertz. By the end of FY 93 we expect to have started studies of FMJTCs at nitrogen temperatures and have fabricated some of the new structures necessary for prototype KITC's. In FY94 the KITC structures fabricated this FY will be characterized and follow-on prototype KITCs will be fabricated. Studies of thermoelectric properties of both heater and thermocouple materials will be initiated. We expect that this work will take at least three years (through FY 95) to complete.

In the future, applications at higher frequencies might well be investigated, working at 50- $\Omega$  characteristic impedances. Eventually, exploitation of superconducting devices for temperature monitoring and converter comparison should lead to standards whose accuracy surpasses the most demanding requirements. Even if these are not attained, it is certain that reduced-noise measurement techniques will be developed that will enable NIST and NASA to make better use of existing room-temperature standards. The techniques to be investigated will also be applicable to other measurement areas, for example IR astronomy.

For NASA, this would mean a nearly perfect standards capability for supporting calibrations of ac voltage and current, but a means of verifying the performance of the FMJTCs as well. Upon the completion of this work, we would anticipate working with NASA to establish copies of the new primary standards in one or more key NASA laboratories and developing procedures to accredit the laboratories to their enhanced capability.



Funding request: This will be a three-year effort. Our funding request, per year, is given below. Note that this project will be heavily supported by NIST internal funding as well (NIST funding will approach \$ 650k per year).

<u>Divisions</u>	<u>Labor</u>	<u>Other Objects</u>	<u>WY's</u>
Electricity	\$ 100k	\$ 20k	0.6
Electromagnetic	\$ 100k	\$ 30k	0.3
Technology			
Total	\$ 200k	\$ 50k	0.9

## NIST Electricity Division Research Proposal to NASA

### Calibration Strategies for Testing Electronic Instrumentation

Principals: T.M. Souders and G.N. Stenbakken

#### Summary:

The objective of this proposal is to apply new error modeling techniques and efficient calibration strategies to reduce the testing requirements of electronic instrumentation. For a pilot demonstration, an instrument in the NASA inventory will be selected whose current metrology support is test-intensive.

#### Technical Background and Strategy:

For a number of years, NIST has been concerned with the increasing challenges of testing complex systems ranging from integrated circuits to full ATE systems. The need to reduce escalating testing costs must be reconciled with increasing demands for quality and reliability in the tested products. To address some of these needs, NIST has developed a comprehensive approach for optimizing the testing of analog and mixed-signal devices [1-4]. The approach has been successfully demonstrated in several studies at the integrated circuit level, where reductions in test time have ranged from a factor of 10 to over 100. Pilot production line evaluation is presently underway for mixed-signal IC applications. More recent work in collaboration with a major instrument manufacturer has shown that the approach also has promise at the instrument level, where reductions by a factor of five or more have been demonstrated for the number of measurements required to fully characterize the instrument [5].

The approach uses a model-based strategy to reduce the test burden posed by many devices. The method exploits the fact that a typical manufacturing process has a relatively small number of significant underlying variables compared to the large number of candidate test points that are often considered necessary. The number and influence of these (otherwise unknown) variables is determined via a singular value decomposition of data taken on many representative devices. From that analysis, an error model is automatically generated that can accurately describe any new device coming off of the production line. To characterize each new part accurately, only three or four times as many measurements are needed as there are variables. The optimum set of test points is automatically selected from the model through matrix transformations that determine the amount of new information that each test point provides. Using the model and the limited test data, accurate predictions can be made of the response of each test device at

all remaining test points. The prediction accuracy is typically comparable to the noise level of the measurement process. Associated statistical confidence bounds for the predictions are computed. Safeguards built into the process flag model errors resulting from changes in the manufacturing process.

The approach just described is tailored to a production line environment in which it is feasible to acquire measurement data on a statistically significant number ( $\sim 100$ ) of representative instruments. However, for a calibration laboratory serving a limited inventory of each instrument type, this approach is not feasible. On the other hand, calibration labs typically maintain records of the calibration history on the inventory, which in principal spans a necessary and sufficient subspace of the full space described by a statistical sample. The work of this proposal is to study, develop and apply models based on records of calibration history of instrument inventories.

#### Expectations:

The near-term goal of this proposal is to develop a formal modeling approach based on calibration records, and to demonstrate the approach on a suitable instrument type in the NASA inventory. Once the model is developed, the NIST test point selection algorithm will be used to establish a reduced test plan for the instruments, which can be evaluated at the next calibration cycle.

Follow-on work will explore adaptive methods that can be used throughout the life cycle of an instrument to enrich or constrain the model as needed with each new calibration, so that the test effort can be adaptively minimized.

The final phase of the work would provide software that NASA calibration lab personnel can use to implement the method. The software would have three functions: to generate the error model from historical calibration data; to select the reduced set of optimized test points, based on required confidence limits supplied by the operator; and, for subsequent calibrations, to predict the response of the test instrument at all *candidate* test points from measurements made at the selected test points, together with estimates of the associated confidence in the predictions.

Funding Requirements for first phase: \$150k

#### References

- [1] G. N. Stenbakken and T. M. Souders, "Test Point Selection and Testability Measures Via QR Factorization of Linear Models," IEEE Trans. I&M, Vol. IM-36, No. 2, June 1987.

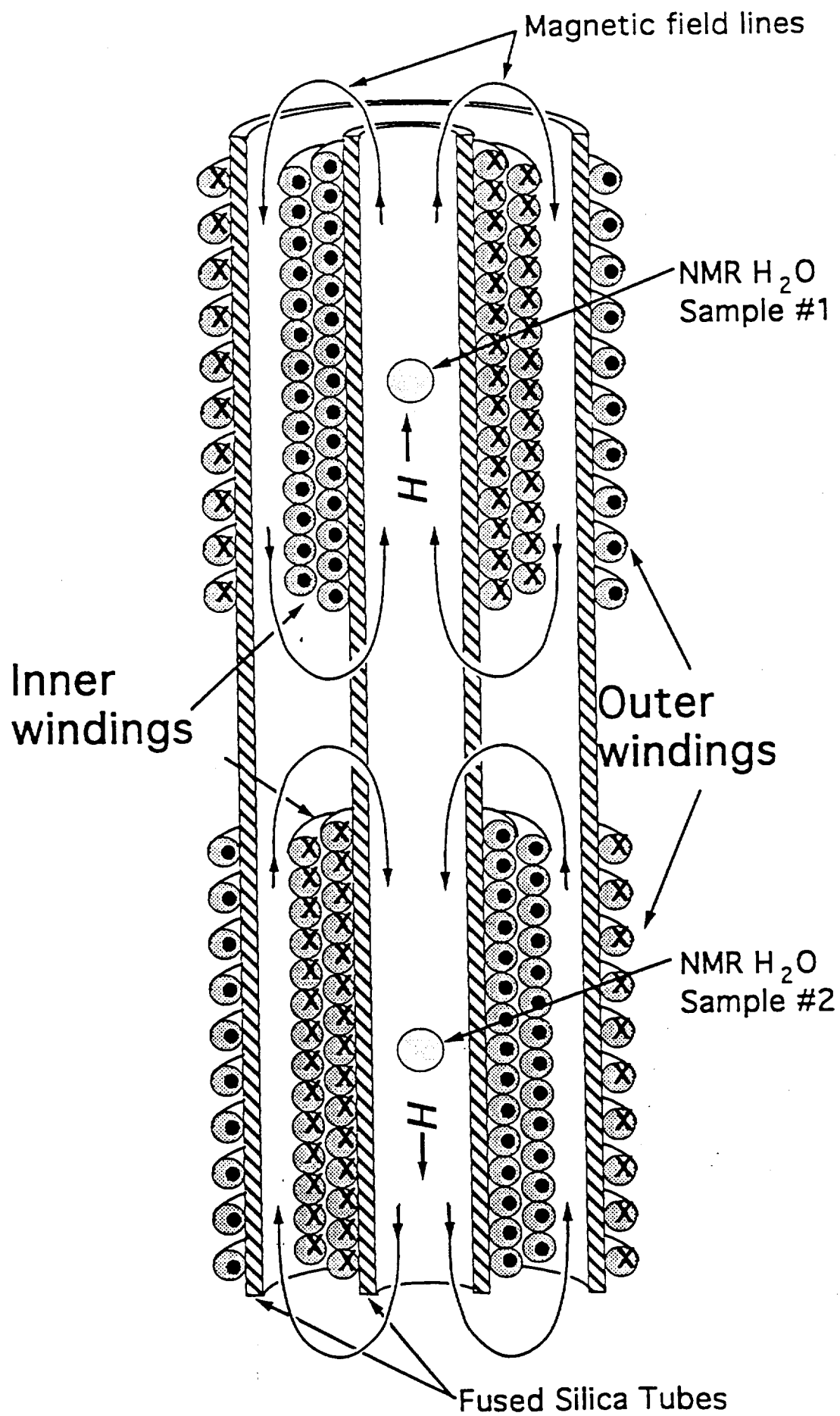
- [2] T. M. Souders and G. N. Stenbakken, "A Comprehensive Approach for Modeling and Testing Analog and Mixed-Signal Devices," 1990 Proc. ITC, IEEE Computer Society Press, Los Alamitos, CA, September 1990.
- [3] G. N. Stenbakken and T. M. Souders, "Linear Error Modeling of Analog and Mixed Signal Devices," 1991 Proc. ITC, IEEE Computer Society Press, Los Alamitos, CA, September 1991.
- [4] T. M. Souders and G. N. Stenbakken, "Cutting the High Cost of Testing," IEEE Spectrum, March 1991.
- [5] A. D. Koffman and B. Stott, "Modeling and Test Point Selection for the Fluke 792A Thermal Transfer Standard," to appear in the proceedings of the 1993 NCSL Workshop and Symposium, Albuquerque, NM, July 1993

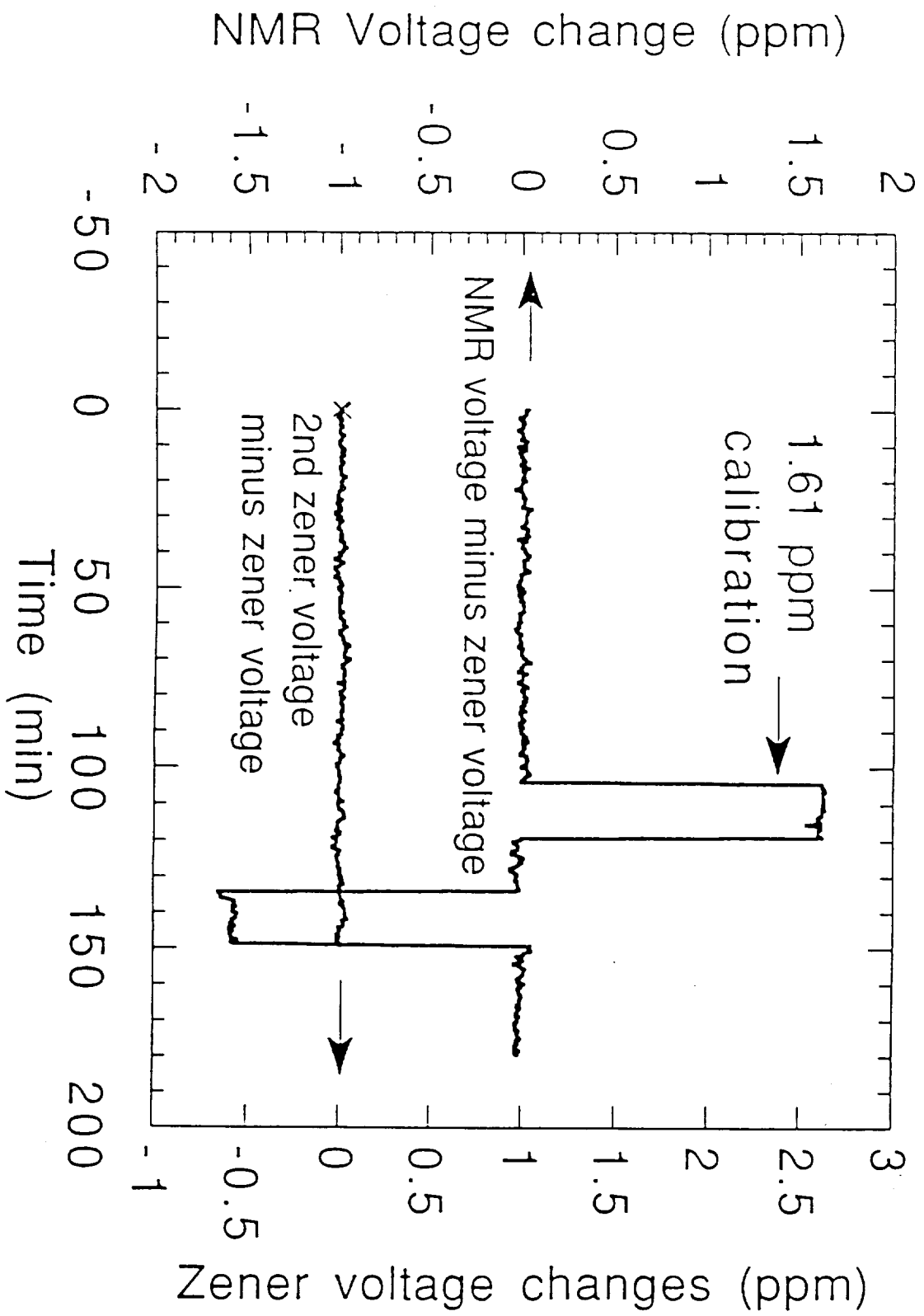
**NIST Electricity Division Research Proposal to NASA**

## **Quantum Electrical Standards**

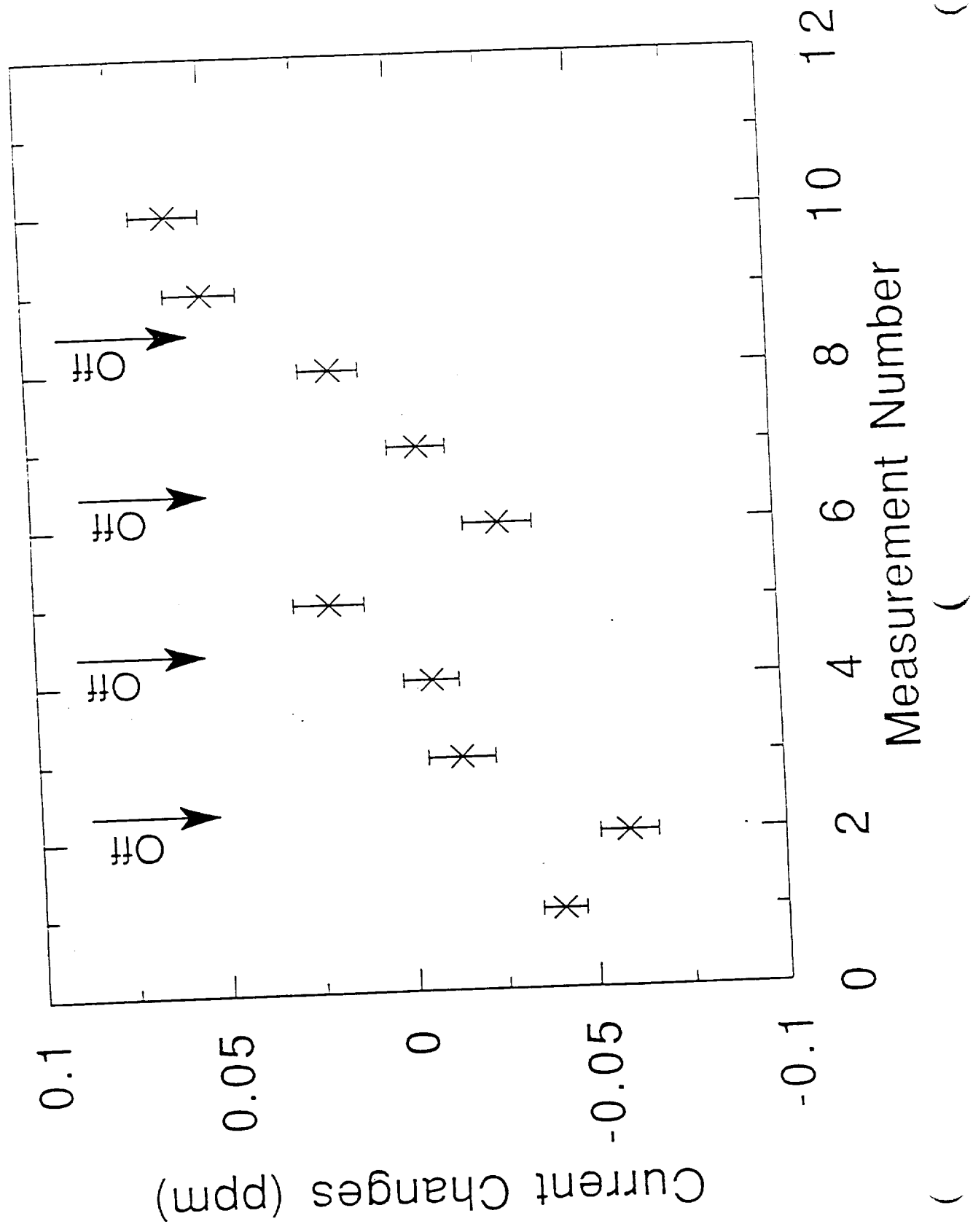
**Intrinsic metrological standards required for space applications.**

**A. F. Clark, M. E. Cage, R. L. Steiner, and E. R. Williams**





# Recovery from turning current off





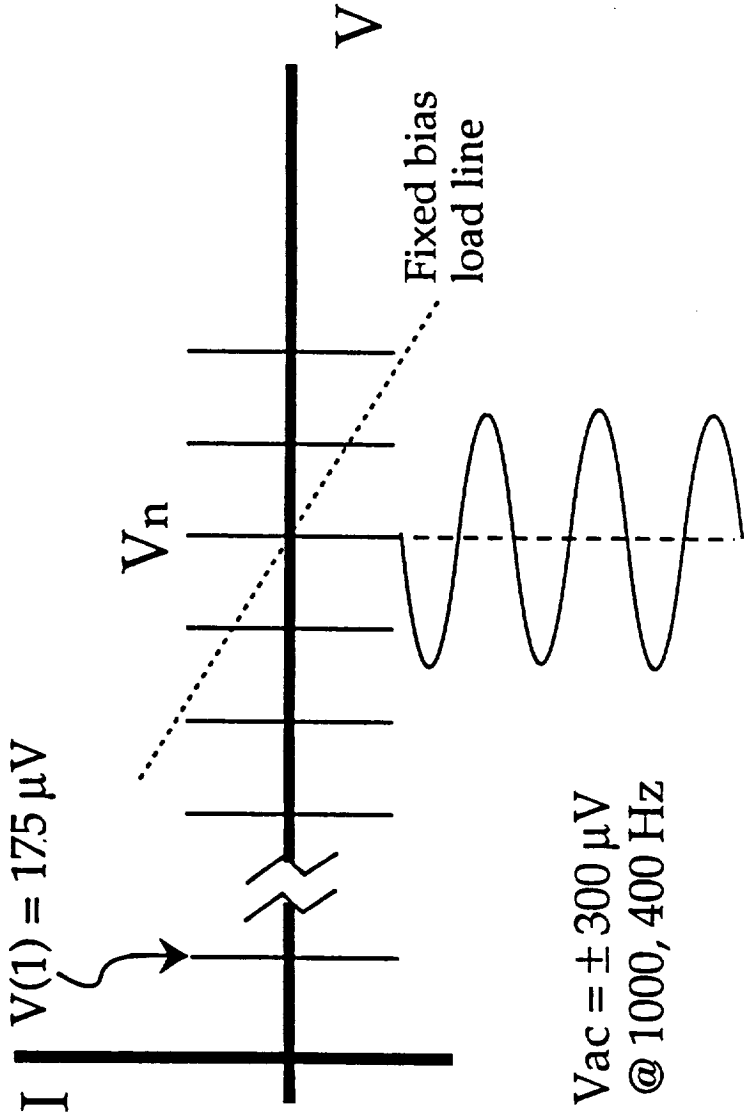
## NMR Current/voltage advantages for NASA

- Transportable Current/ Voltage reference
- Quieter than zener
- More accurate than zener
- Can turn off
- Without shields, it is also be a vector magnetometer.  
~0.1 nT

# AC Voltage from a Josephson Array

Theory: { Josephson Effect  $V_n = f n \frac{h}{2e}$   
AC voltage from  
varying frequency  $\Delta V = V_n \frac{\Delta f}{f_0}$

Experiment: { Apply FM modulation  $f = 85 \text{ GHz} \pm 25 \text{ MHz}$   
@ 1000, 400 Hz rate  
Choose 1-V step  $n \approx 5700$



Result: {  $V_{ac} = \pm 300 \mu V$   
@ 1000, 400 Hz

# Josephson-Array Derived AC Signals

## Potential

- An ultra-low noise source of calibrated small AC signals
- An ideal FM demodulator

## Research to understand the limitations of:

- 70-95 GHz FM modulation electronics
- Array stability, critical current and frequency response
- Calibrations using small signals

## Applications

- High precision calibration of small signal AC devices, i.e. vibration sensors
- Direct use as a vibration sensor

Array FM demodulation to detect micro-vibrations on  
a microwave cavity

Tracking of a small AC signal with low noise array

# Quantum Hall Effect Devices

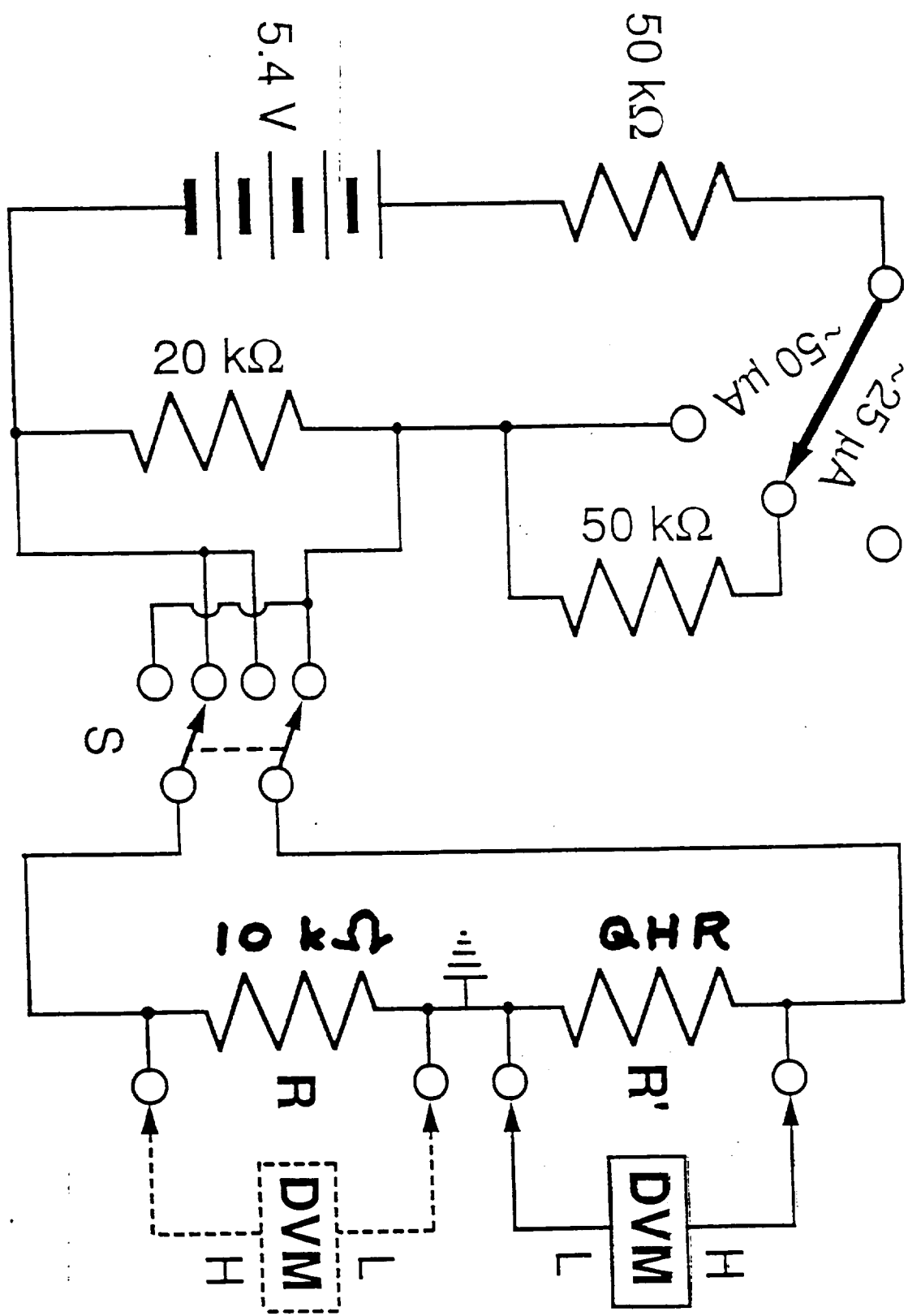
## *for DC Resistance Standards*

### • High Current Devices:

- > Present devices operate at  $25\ \mu\text{A}$ .
- > Increasing current will decrease time required to reach desired level of uncertainty in resistor calibrations.
- > Present samples exhibit dissipative flow at high currents
- > This problem may be overcome by varying sample and contact geometry.

### • High Temperature Devices:

- > Present devices operate at temperatures  $< 1.2\text{K}$
- > Increasing temperature at which device operates will permit use of simpler and less costly cryogenic systems.
- > Investigate effect of heterostructure design and other device parameters on the temperature coefficient of the devices.



# DVM Method Measurements

Difference (ppm) from scaling results

Ratio	DVM 3	DVM 4
1 : 1	0.018	0.007
1 : 1	0.000	0.004
2 : 1	0.012	0.008
10 : 6.4532	0.066	0.070
10 : 6.4532	0.064	0.055
12.9064 : 10	0.002	0.012

## PROJECT OBJECTIVES

Develop a prototype quantum Hall effect (QHE) DC resistance standard

- 0.1 ppm accuracy
- Monitors 10 k $\Omega$  resistors

Address effect of sample processing parameters on performance of QHE devices

- Produce QHE devices that operate above 1.2 K to eliminate need for expensive refrigerators

## BENEFITS

- An intrinsic dc resistance standard
- Provides absolute accuracy to 0.1 ppm
- Solves scaling problem to 10 k $\Omega$
- Accuracy verified with 10 k $\Omega$  MAPs
- Relatively easy to assemble
- Technician can operate it
- QHE devices that operate above 1.2 K to eliminate need for expensive refrigerators



# NIST Electricity Division Research Proposal to NASA

## Quantum Electrical Standards

Project	Labor	FY94 Equipment	WY's	Labor	FY95 Equipment	WY's	Labor	FY96 Equipment	WY's
Quantum Hall	\$ 100k	\$ 20k	0.6	\$ 120k	\$ 20k	0.6	\$ 140k	\$ 20k	0.8
AC JJ volt	\$ 80k	\$ 40k	0.5	\$ 100k	\$ 20k	0.6	\$ 140k	\$ 20k	0.8
NMR current	\$ 100k	\$ 20k	0.6	\$ 100k	-	0.6	-	-	-
sub total	\$ 280k	\$ 80k		\$ 329k	\$ 40k		\$ 280k	\$ 40k	
Total	\$ 360k			\$ 380k			\$ 320k		



# CENTER REPORTS



# NASA Ames-Moffett Instruments by Discipline FY92

B	Pressure and Vacuum	2,851
D	Dimensional	2,961
M	Mass, Force & Torque	2,165
H	Temperature & Humidity	497
E	Electrical	14,449
		-----
		22,923

Total Number of Instruments Serviced:	6,638
Total Number of Hours:	9,947

## NASA Ames-Moffett Actions Taken FY92

Action Code	Number	Description	Ave Hours
A	111	Acceptance Check	1.9
C	3,426	Calibration Checked	1.5
F	93	Functional Check	.7
I	229	Returned Unserviced	.5
J	161	Beyond Economical Repair	.9
L	65	Limited Calibration	1.7
M	25	Preventive Maintenance	1.8
N	10	Modifications	4.0
Q	239	Adjust and Calibrate	1.8
R	84	Repair	2.4
S	3	Repair & Limited Cal	5.3
T	589	Repair & Calibrate	3.7
V	33	Clean, Adjust, & Calibrate	1.2
X	1,521	Clean & Calibrate	.8
Z	30	Clean, Repair, Limited Cal	2.9
1	19	Acceptance Check Reject	1.6
	=====		
	6,638		

# NASA Ames-Moffett Cal/Repair Summary FY92

## Recall In Cycle

	Calibrations		Repairs	
	Electronic	Mechanical	Electronic	Mechanical
Oct '91	334	308	31	12
Nov	292	82	32	10
Dec	127	96	52	2
Jan '92	121	82	19	2
Feb	86	89	20	1
Mar	105	73	30	11
Apr	112	105	29	3
May	146	116	23	5
Jun	119	68	26	10
Jul	265	187	31	4
Aug	169	426	25	5
Sep	172	63	18	0
	=====	=====	=====	=====
Total	2,048	1,695	336	65

## Recall Out of Cycle

	Calibrations		Repairs	
	Electronic	Mechanical	Electronic	Mechanical
Oct '91	0	4	0	0
Nov	5	15	0	0
Dec	7	7	3	1
Jan '92	57	41	13	2
Feb	137	59	22	3
Mar	179	54	36	1
Apr	95	21	22	4
May	137	38	22	4
Jun	114	23	22	0
Jul	136	44	28	1
Aug	144	187	19	18
Sep	110	74	17	2
	=====	=====	=====	=====
Total	1,121	567	204	36

# NASA Ames-Moffett Cal/Repair Summary FY92

## Non-Recall

	Calibrations		Repairs	
	Electronic	Mechanical	Electronic	Mechanical
Oct '91	20	3	8	0
Nov	11	2	8	1
Dec	39	5	7	2
Jan '92	50	24	27	2
Feb	33	15	11	1
Mar	40	34	20	1
Apr	60	3	23	0
May	113	3	9	0
Jun	18	7	13	1
Jul	8	4	11	0
Aug	79	1	7	1
Sep	23	3	17	1
	====	====	===	===
Total	494	104	161	10

65 Electrical Items 'BER'

96 Mechanical Items 'BER'

156 Electrical Items 'Returned As Is'

62 Mechanical Items 'Returned As Is'

## NASA Ames-Moffett % Out of Tolerance FY92

	Recall (in cycle)		Recall (out of cycle)		Non-Recall	
	Elect	Mech	Elect	Mech	Elect	Mech
Oct '91	0.3	3.2	0.0	75.0	0.0	100.0
Nov	0.3	2.4	0.0	26.7	0.0	0.0
Dec	2.5	3.1	0.0	0.0	0.0	0.0
Jan '92	.8	0.0	1.8	9.8	0.0	0.0
Feb	3.5	2.2	3.6	1.7	0.0	0.0
Mar	5.7	0.0	1.1	0.0	0.0	0.0
Apr	5.4	0.0	3.2	0.0	1.7	0.0
May	.7	1.7	1.5	5.3	0.0	0.0
Jun	1.7	0.0	3.5	0.0	5.6	0.0
Jul	1.5	0.5	0.7	0.0	0.0	0.0
Aug	3.6	0.5	3.5	1.6	0.0	0.0
Sep	1.7	0.0	2.7	2.7	4.3	33.3





**Goddard Space Flight Center  
Metrology Program Status Report  
for  
Fiscal Year 1992**

**Louis A. Thomas**

**16th Annual NASA Metrology Workshop  
NIST  
Gaithersburg, Maryland**

**April 20 to 22 1993**

## **SUMMARY**

Paramax Systems (A Unisys Co.) provides metrology services for Goddard Space Flight Center under the technical management of the Office of Flight Assurance.

In fiscal year '92 several changes took place within the Office of Flight Assurance and Paramax Systems. Bob Sutton retired in July '92, leaving the position vacant until Louis Thomas' recent appointment. David Miller, the metrology engineer left in May '92 and was replaced by Herman Douthit. While key personnel and numerous lab personnel changes took place, Paramax Systems continued to have a productive year.

The lab installed SPECTRUM distribution amplifiers at each work bench to provide continuous access to the lab frequency reference standard.

The total number of items calibrated and or repaired was 10,168. TECR accounted for 4,154 units, the TCS accounted for 4,038, and Dimensional accounted for 1,976.

195 pieces of equipment were returned to the original manufacturer for calibration or repair.

174 pieces of equipment were delayed for parts.

## **TECR ACTIVITIES**

The Test Equipment Calibration and Repair section is presently staffed by fourteen full-time and one part-time personnel. This includes a supervisor, a truck driver, and a metrology engineer.

The average hours per event in the laboratory were; 3.70 hours per repair and 2.43 hours per calibration for an overall average of 2.82 hours per event.

The average calibration time for all events using the Transportable Calibration System was .77 hours. Fifty five percent or 2216 units were calibrated using automated procedures. There was an 11 % failure rate (out of cal.).

\* Dimensional calibration lab activities.

## **DIMENSIONAL CALIBRATION LAB**

The Dimensional Calibration Lab performed a total of 1976 calibrations during FY 92 which was an increase of 522 over FY 91. One thousand eight hundred (1,800) calibrations were hand tools (micrometers, calipers, indicators, etc.) and 84 calibrations were machine tools.

## **EQUIPMENT REPLACEMENT AND UPDATING**

The TECR laboratory was updated this year with the following equipment.

1).	TEK CG5011	O'scope Calibrator	\$21,400
2).	TEK SG5010	Low Distortion Oscillator	\$ 4,800
3).	H/P 16074A	Std Resistor Set	\$ 3,000
4).	H/P 3458A	8.5 Digit Multimeter	\$ 7,300
5).	H/P 6060A	Electronic Load	\$ 8,200
6).	Fluke 6061A	Synthesized Generator	\$ 6,300
7).	Boonton 92EA	RF Millivoltmeter	\$ 2,000
8).	Biddle 72-6346-1	Hi-Res. Decade	\$ 3,200
9).	Jofra D55SE	Temperature Calibrator	\$ 4,700
10).	Jofra 650SE	Temperature Calibrator	\$ 4,000

The mechanical inspections laboratory was updated this year with the following equipments:

### Dimensional Calibration Equipment

- Pratt & Whitney External & Internal Supermicrometers, 0 to 10 inch (250 mm), 10 microinches (.00025mm) resolution.
- Federal Gage Block Comparator 0-4 inch (100mm), accurate within 0.2 microinches (.02 micrometer).
- K&E Autocollimator, 0 to 100 feet, direct reading to 0.2 seconds of arc
- Moore Universal Measuring Machine, 18 inch x, 11 inch y, 14 inch z, 5 microinch resolution.

## STAFFING

### NASA

Technical Monitor 1

### PARAMAX

#### TECR

Supervisor	1
Metrologist	1
Technicians	11 + 1 part time
Courier/Driver	1

#### GMIS

Administrator	1
Data Clerk	1

### DIMENSIONAL CALIBRATION

Calibration Technician's	1.5
--------------------------	-----

**GODDARD SPACE FLIGHT CENTER**  
**TEST EQUIPMENT CALIBRATION AND REPAIR ACTIVITY**  
**ANNUAL FY 1992**

	TOTAL EVENTS	AVG. HOURS PER EVENT
Repair	1725	3.70
Calibration	3873	2.43
Total	5598	2.82

Total Jobs Completed:

4154

**TRANSPORTABLE CALIBRATION SYSTEM**  
**ANNUAL REPORT, FY 1992**

Category Code	Type	Calibrated	% of Total	# of Units Failed	% of Category
01	Counters	222	5.5%	23	10.0%
02	Oscilloscopes	711	17.6%	63	8.0%
03	Plug-In (Scope)	911	22.6%	62	6.0%
07	Amplifiers	101	2.5%	5	4.0%
09	Power Supplies	462	11.4%	112	24.0%
11	DVM/DMM	708	17.5%	68	9.0%
12	AVM/VTVM	79	2.0%	14	17.0%
13	Generators	185	4.6%	13	7.0%
14	Meters	524	13.0%	62	11.0%
15	Decades	135	3.3%	7	5.0%

Total Calibrated: 4038

Total Failed: 429

Hours Charged 3092

Hours/Unit: 0.77

Failure Rate: 11%

2216 Units, 55%, were calibrated using automated calibration procedures.

**GODDARD SPACE FLIGHT CENTER**  
**TEST EQUIPMENT CALIBRATION AND REPAIR ACTIVITY**  
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**CENTER STATUS REPORT**  
**JET PROPULSION LABORATORY**

**STEVE BEDNARCZYK**

**16TH NASA METROLOGY AND CALIBRATION WORKSHOP**

**April 20-22, 1993**

## **ABSTRACT**

Staffing adjustments continued during 1992 with emphasis placed on improving quality technical capability/ability. This resulted in hardware technical resource within the Calibration Laboratory. On-site maintenance improved in both office machine and safety program instrumentation which was started last year and a new on-site capability was established for the calibration of Microwave Network Analyzers. This resulted in a substantial savings in the maintenance and calibration holding accounts

## **II. CALIBRATION PROGRAM OVERVIEW**

The Instrument Services Group of the Instrumentation section is responsible for the quality calibration, maintenance and repair of JPL controlled - government owned - instruments and equipment. Most General Purpose Test Equipment is managed by the sections Loan Pool and is maintained by one of the sections laboratories as follows;

Measurement Standards Laboratory establishes primary standards †and NIST traceability requirements and calibrates JPL working standards.

Transducer Laboratory calibrates physical and electromechanical working standards and instruments.

Calibration and Instrument Services Laboratory provides general purpose test equipment calibrations and user hardware consultation. Equipment calibration recalls, an technical library and an parts facility are also managed here.

Loan Pool provides hardware/software interface service as an adjunct to their portable computer rentals. Software programming is provided through the sections Measurement Technology Center.



### III. JPL ACTIVITIES

#### 1. INSTRUMENT LOAN POOL ACTIVITIES

	FY 91	FY 92
AVG. LOAN POOL INVENTORY	6392	6597
AVG. INSTRUMENTS ON LOAN	3209	3431
AVG. % OF INVENTORY ON LOAN	50%	52%
NUMBER OF NEW INSTRUMENTS ACQUIRED		
LOAN POOL INSTRUMENTATION	671	165
LOAN POOL COMPUTERS	NA	102
COST OF NEW INSTRUMENTS ACQUIRED		
LOAN POOL INSTRUMENTATION	\$2119K	\$2406K
LOAN POOL COMPUTERS	NA	\$ 516K

#### 2. CALIBRATION LABORATORY ACTIVITIES

The three laboratories calibrate electronic, electro-mechanical, physical and safety related instruments and systems. Calibrations range from oxygen monitors to 40 GHz networks; DC to laser standards. Most calibrations are performed in the laboratory environment, however, network analyzers, safety related systems and controllers are usually calibrated on site. A review of calibration events is compiled below with associated charts attached as figures

	FY 91	FY 92	DELTA
ELECTRONIC CALIBRATIONS AND REPAIRS	3575	4170	+16.6%
TRANSDUCER CALIBRATIONS	417	749	+79.6%
OFFICE MACHINES	755	1194	+58.2%
TOTALS	4747	6113	+28.8%

Increases in calibration and repair events noted above are directly attributable to staffing efforts in late 1991 and early fiscal 1992 and the Loan Pool general purpose instrumentation inventory review to reduce excess items. Office machine gains were accomplished through better time management and accountability methods.

#### IV. CALIBRATION PROGRAM ANALYSIS

##### A. STAFF

TABLE OF LABOR CATEGORIES AND DISTRIBUTIONS

	JPL	Contract	
Program Management	3	1	
Engineering	3	0	
Technician	2	7	
Technician support	2	2	
Clerical & Logistic	1	7	
Totals	11	17	28

##### B. WORK ANALYSIS

###### 1. CALIBRATION AND REPAIR

Calibration and repair events increased in fiscal 1992 to 6113 , a 28 percent increase over fiscal 1991. Our continuing productivity improvements are due principally to the attention paid to establishing the proper technical mix to support our varied workload and to our "customer satisfaction" attitude. Substantial reductions in "OFF" laboratory vendor services, careful workload and customer requirement reviews and especially strong communications within and between departments aided our efforts. Network analyzer on-site calibrations and in-house customer user training helped take our customer service message to laboratory users.

###### 2. LOAN POOL

### **3. CONDITION OF EQUIPMENT RECEIVED FOR CALIBRATION AND REPAIR**

52.2% were received within tolerance, no adjustment required

11.1% were within tolerance, but were adjusted

36.7% were out of tolerance and were adjusted/repared

### **V. CALIBRATION SYSTEM DEVELOPMENTS**

Automatic temperature calibration and characterization system developed for PRT and thermocouple calibrations of custom manufactured thermocouples and PRTs. This new capability provides detailed calibration and characterization of these custom thermocouples and PRTs and directly reduced customer downtime and decreased measurement uncertainty.

Transducer Laboratory added an automatic vacuum calibration system increasing JPL capability and reducing the necessity of vendor vacuum calibrations.

The Calibration Laboratory implemented an on-site Microwave Network Analyzer calibration program. A Microwave Standards MAP to provide microwave standards calibrations of the highest accuracy was also developed. This combined capability reduced customer downtime and increased customer satisfaction and measurement capabilities.

### **VI. EQUIPMENT REPLACEMENT AND UPDATING**

A significant Loan Pool product in FY 92 was the addition of computer controllers and software support to implement automatic control of test instrumentation and processes. As noted in paragraph 3.1 over \$500K was expended on computational products such as PC and Macintosh controllers and LABVIEW and HP-VEE software to aid customers in the automation of their projects and experiments.

Additionally, calibration instrumentation in the Transducer and Calibration Laboratories improved vacuum calibration and microwave power and attenuation calibration capabilities and uncertainties.

## **VII. CALIBRATION PROCEDURES AND SOFTWARE DEVELOPMENT**

Software developed for the technical library resulted in streamlined manual location and significant reduction in time previously lost to improperly placed or misplaced manuals. Additionally, software modifications aided in parts ordering and tracking helping to reduce repair turn around time.

A calibration recall and management system software package was added to the Calibration Laboratory which will be fully implemented in fiscal 1993.

## **VIII. TRAINING**

An effort was made to increase the skill level of the technician staff - especially with recent technical developments in the instrumentation field. Two contractor technicians attended NASA soldering school, and one contractor technician attended an Oscilloscope calibration class at Tektronix. Two individuals attended the Accelerometer calibration course offered at the MSC. One contractor technician attended a microwave calibration techniques course. Two staff members attended courses in RMB programming. Several members of the staff are scheduled to attend the 1993 Measurement Science Conference in February in Anaheim, CA. We hope to maintain the current level of training in FY93 to increase the staff capability and decrease the amount of calibration work being referred to outside vendors.

## **IX. CERTIFICATION OF REFERENCE STANDARDS**

JPL maintains reference standards and uses the services of NIST for traceability of the national standards in thermal converters, capacitance, resistance, and inductance.

Temperature is maintained through a triple-point cell and other intrinsic materials.

Relative humidity traceability is maintained through a General Eastern 1500 which is sent to the factory for periodic calibration.

Pressure and force standards are traceable to national standards through the Naval Weapons Station Standards Laboratory in Pomona, CA.

Voltage is maintained through the regional volt MAP which is under the direction of NIST.

Time and frequency standards are traceable to the USNO, Washington D.C., through the LORAN chain.

Automated Radio Frequency Techniques Group (ARFTAG) sponsored the microwave Measurement Assurance Program was joined with measurements accomplished thru NIST participation.

## **X. PROBLEM AREAS**

There were no significant problem areas to report this FY.

## **XI. ACTIVITIES**

### **A. FUTURE ACTIVITIES.**

1. Develop the capability to perform Microwave attenuation measurements.
2. Develop the capability to perform Ultra-Violet temperature measurements.
3. Develop the capability to perform calibrations on Fiber-Optic Power Instruments.
4. Upgrade the Accelerometer Calibration Test Equipment.

**JPL STANDARD LAB.  
MEASUREMENT CAPABILITIES**

6/18/93 ( )  
By: Steve Lewis/ L.Kirk

MEASUREMENT PARAMETER	RANGE	MEASUREMENT UNCERTAINTY (+/-)	STANDARD OR METHOD
<u>DC VOLTAGE</u>	Standard Cells 1.018 V	0.5 PPM	Difference Measurement against Saturated Standard Cells
	10 V	0.5 PPM	Difference Measurement against Solid State Reference STDS.
	0.1V -1 kV	2 PPM	Difference Measurement against DC Calibrator and Divider
	1-10 kV	0.01%	Voltage Divider and DVM.
<u>DC RATIO</u>	2-100 V	1 PPM	Subdivided Resistors
	100-1000 V	5 PPM	Subdivided Resistors
	1-10 kV	0.01%	High Voltage Dividers
Variable	0-300 V	0.5 PPM Terminal Linearity	Kelvin-Varley Divider

**JPL STANDARDS LAB.  
MEASUREMENT CAPABILITIES**

MEASUREMENT PARAMETER	RANGE	MEASUREMENT UNCERTAINTY (+/-)	STANDARD OR METHOD
<u>DC CURRENT</u>	1-1000 pA	1%	Standard Resistors/Nanovoltmeter
	1 nA- 0.1 mA	0.01%	" "
	0.1 mA-1 A	50 PPM	" "
	1-100 A	0.01%	Standard Multirange Shunt/DVM
<u>RESISTANCE</u>	0.001,0.01,0.1 Ohm	2 PPM	Comparator Bridge / Thomas Res.
	1 Ohm	1 PPM	" "
	10 , 100, 1K Ohm	2 PPM	Substitution with NBS Type Resistors
	10 Kohm	2 PPM	Substitution with STD. Resistor
	100 Kohm	5 PPM	" "
	0.1-10 Mohm	10 PPM	Substitution using Kelvin Bridge and Standard Resistors



**JPL STANDARDS LAB.  
MEASUREMENT CAPABILITIES**

MEASUREMENT PARAMETER	RANGE	MEASUREMENT UNCERTAINTY (+/-)	STANDARD OR METHOD
<u>RESISTANCE</u> (Cont.)	100 Mohm	20 PPM	Substitution using Kelvin Bridge and Standard Resistors
	100-1000 Mohm	0.1%	Substitution using Megohm Bridge and Standard Resistors
	1-1000 Gohm	0.25%	" "
	10 Tohm	1%	" "
<u>AC VOLTAGE</u>	2 $\mu$ V-1 mV (35 Hz-10 kHz)	3%	RMS Differential Voltmeter
	1 mV-0.5 V (30 Hz-20 kHz)	0.5%	Ratio Transformer and RMS Differential Voltmeter
	0.5-100 V (20 Hz-100 kHz)	0.02%	Thermal Transfer Standard
	100-500 V (20 Hz-100 kHz)	0.04%	" "
	1-100 V (100 kHz-1 MHz)	0.1%	" "

**JPL STANDARDS LAB.  
MEASUREMENT CAPABILITIES**

(Cont.)

MEASUREMENT PARAMETER	RANGE	MEASUREMENT UNCERTAINTY (+/-)	STANDARD OR METHOD
<u>AC RATIO</u>	0-1E6 (30 Hz-1 kHz)	10 PPM Terminal Linearity	Ratio Transformer
<u>AC CURRENT</u>	0.007, 5-40 A (20 Hz- 20 kHz)	0.01%	Thermal Transfer Ammeter
<u>AC POWER</u>	0-120 W (60 Hz) 0-1 kW (0-10 kHz)	0.25% " "	Wattmeter Current-Potential/Phase Method
<u>CAPACITANCE</u> (3-Terminal @ 1 kHz)	0.01 pF	0.03%	Substitution using Capacitance Bridge and Standard Capacitors
	0.1-1000 pF	0.012%	" "
	1000 pF Hermetically Sealed	20 PPM	" "

JPL STANDARDS LAB.  
MEASUREMENT CAPABILITIES

(Cont.)

MEASUREMENT PARAMETER	RANGE	MEASUREMENT UNCERTAINTY (+/-)	STANDARD OR METHOD
<u>CAPACITANCE</u> (2-Terminal @ 1 kHz)	1000 pF-0.5 uF	0.15%	Substitution using Capacitance Bridge and Standard Capacitors
	0.5-200 uF	0.1%+1 cnt	Capacitance Meter
	200 uF-199.9 mF	1%	" "
<u>INDUCTANCE</u>	.1-100 uH	0.2%+0.1 uH	Inductance Bridge
	100 uH	0.3%	Substitution using Inductance Bridge and Standard Inductors
	1 mH-10 H	0.15%	" "

**JPL STANDARDS LAB.  
MEASUREMENT CAPABILITIES**

MEASUREMENT PARAMETER	RANGE	MEASUREMENT UNCERTAINTY (+/-)	STANDARD OR METHOD
<u>MAGNETICS</u> (Axial and Transverse)	0-0.0015 Tesla	1%	Standard Reference Coil
(Transverse)	0.03 Tesla	1%	Standard Reference Magnet
(Transverse)	0.1 to 1.4 Tesla	0.5 %	" "
(Axial)	0.01 to 0.05 Tesla	1 %	" "
1 gauss=.0001 Tesla			
<u>FREQUENCY</u>	Integral and Sub- Multiple of 100 kHz	5 Parts in 10 <sup>13</sup>	Cesium Frequency Standard, Frequency Difference Meter, and/or Electronic Counter
	1 Hz-0.5 GHz	0.01-1 %	" "

**JPL STANDARDS LAB.  
MEASUREMENT CAPABILITIES**

MEASUREMENT PARAMETER	RANGE	MEASUREMENT UNCERTAINTY (+/-)	STANDARD OR METHOD
<u>Q-FACTOR</u> (Q Indicated) $Q = 2\pi fL/R$	5-300	7 % @ 22 k-30 MHz 10 % @ 30-70 MHz	Q Meter (22 kHz-70 MHz)
	300-600	10 % @ 22 k-30 MHz 15 % @ 30-70 MHz	" "
	600-1000	15 % @ 22 k-30 MHz 20 % @ 30-70 MHz	" "
	99-154	4 % @ 50-150 kHz	Substitution using Q Meter and Q Standards
	159-205	4 % @ 150-450 kHz	" "
	189-234	4 % @ 0.5-1.5 MHz	" "
	169-238	4% @ 1.5-4.5 MHz	" "
	217-240	4% @ 5.0-15 MHz	" "
	195-257	2 % @ 15-45 MHz	" "

**JPL STANDARDS LAB.  
MEASUREMENT CAPABILITIES**

MEASUREMENT PARAMETER	RANGE	MEASUREMENT UNCERTAINTY (+/-)	STANDARD OR METHOD
<u>TIME</u>	1 $\mu$ S-10 S	1 nS	Electronic Counter
	Time of Day	.1 $\mu$ S referred to UTC (USNOBS. Approximation)	Time Code Generator
<u>TEMPERATURE</u>	1.8 to 30 k	0.25 k	Comparison with NIST traceable: Standard Rhodium Iron Resistor
	13.8 to 300 k	0.1 k	Capsule Standard Platinum Resistance Thermometer
	77 to 800 k	0.01 k	Long Stem Platinum Resistance Thermometer
	273 to 1373 k	0.2 k	Long Stem High Temperature Platinum Resistance Thermometer
	1373 to 1700 k	2.0 k	Thermocouples" "

**JPL STANDARDS LAB.  
MEASUREMENT CAPABILITIES**

MEASUREMENT PARAMETER	RANGE	MEASUREMENT UNCERTAINTY (+/-)	STANDARD OR METHOD
<u>TEMPERATURE</u> (Cont)	234.316 k	0.006 k	Triple Point of Hg
	273.16 k	0.0001 k	Triple Point of H <sub>2</sub> O
	505.08 k	0.01 k	Freezing Point of Sn
	692.68 k	0.009 k	Freezing Point of Zn
	933.47 k	0.2 k	Freezing Point of Al
	1357.77 k	0.3 k	Freezing Point of Cu

**JPL STANDARDS LAB.  
MEASUREMENT CAPABILITIES**

MEASUREMENT PARAMETER	RANGE	MEASUREMENT UNCERTAINTY (+/-)	STANDARD OR METHOD
<u>TEMPERATURE</u> (Cont.)  (Non-Contact)	800-2300 C	2-6 C	Optical Pyrometer and STD. Lamp
	3530 C	20 C	Pyrometric Arc Source
	-10 to 100 C	0.2 C	Black Body Source
	100-1200 C	0.2-2.4 C	" "



**JPL STANDARDS LAB.  
MEASUREMENT CAPABILITIES**

MEASUREMENT PARAMETER	RANGE	MEASUREMENT UNCERTAINTY (+/-)	STANDARD OR METHOD
<u>FORCE</u>	(0-10000 Lbs., 0-44500 Newtons)	0.037 % I.V.	Ratio and Comparison with NIST Certified Mass
	(0-60000 lbs., 0-266893 Newtons)	0.02 % F.S.	Comparison with NIST Certified Mass
<u>VACUUM</u>	10 <sup>-8</sup> to 10 <sup>3</sup> Torr	10 <sup>-8</sup> to 10 <sup>-4</sup> ± 1 % of Rdg. 10 <sup>-4</sup> to 10 <sup>3</sup> ± 0.05 % of Rdg.	Comparison with NIST certified Standards
	(0-825 mm-Hg, 0-110 kPa )	0.05 mmHg Res.	Comparison with NIST Certified Manometer

**JPL STANDARDS LAB.  
MEASUREMENT CAPABILITIES**

MEASUREMENT PARAMETER	RANGE	MEASUREMENT UNCERTAINTY (+/-)	STANDARD OR METHOD
<u>PRESSURE</u>	(0-12500 PSI., 0-86184 kPa)	0.01 % I.V.	NIST Certified Piston Gage
	(0-2500 PSI., 0-17237 kPa)	0.025 % F.S.	" "
<u>Trace Moisture</u> (Dew/Frostpoint in GN )	-80 to 20 C	0.5 C	Hygrocomputer and Optical Chilled Mirror Hygrometer
<u>RELATIVE HUMIDITY</u> (Humidity Environ. at selectable Temp . from 0-70 C)	10-95 % R.H.	1.0 % R.H.	Dual Pressure Humidity Generation System

**JPL STANDARDS LAB.  
MEASUREMENT CAPABILITIES**

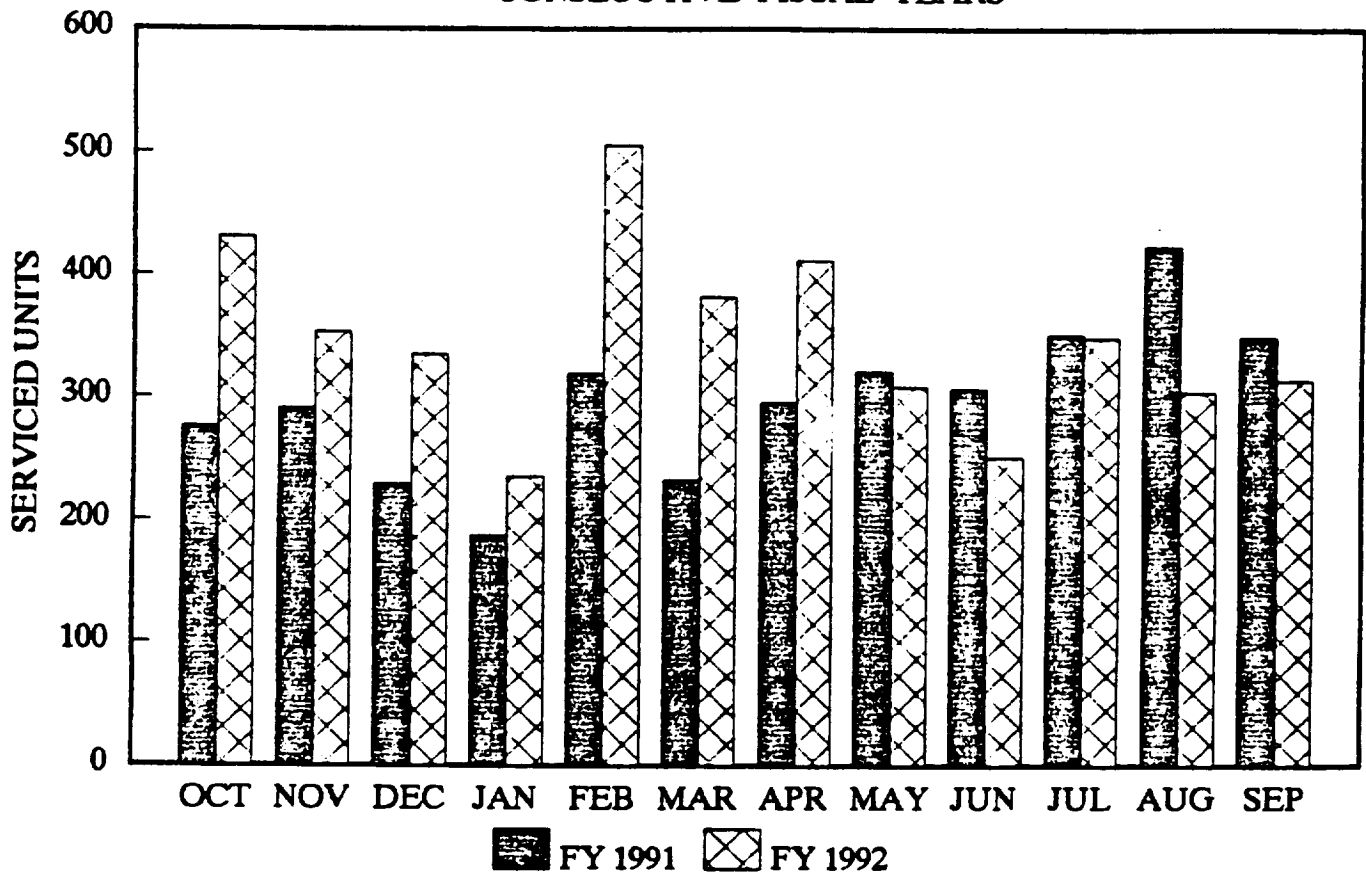
MEASUREMENT PARAMETER	RANGE	MEASUREMENT UNCERTAINTY (+/-)	STANDARD OR METHOD
<u>ACCELERATION</u> (Piezoelectric / Piezoresistive Accelerometer pickup sensitivity & Freq. Response Measurements)	1g Peak-100 g Peak (5 Hz-10 kHz)	2 % @ 10 Hz-9 kHz 4 % @ 9-10 kHz	Vibration System / Back to Back Comparison Method
	0.25-1.00 g peak (1-200 Hz)	1 % @ 100 Hz 1.5 % @ 1-200 Hz	Automated Accelerometer Calibration System / Back to Back Comparison Method
<u>GAS CONCENTRAL</u>	17.5-20.9 % Oxygen by Volume; Balance of Nitrogen.	0.25 % O <sub>2</sub> by Volume	Calibration Gas Delivery System utilizing STD. Reference Materials

**JPL STANDARDS LAB.  
MEASUREMENT CAPABILITIES**

MEASUREMENT PARAMETER	RANGE	MEASUREMENT UNCERTAINTY (+/-)	STANDARD OR METHOD
<u>SPECTRAL RADIO- METRIC</u>			
Wavelength	200 nm - 20 $\mu$ m	0.1 % of Reading or 1 nm whichever is greater.	Double Grating Monochrometer
Radiance	250 nm - 6.0 $\mu$ m  > 6.0 $\mu$ m	3.0 %  TBD	Tungsten Ribbon Filament Lamp  Blackbody Standards
Irradiance	200 nm - 400 nm 250 nm - 2.5 $\mu$ m 2.5 $\mu$ m - 6.0 $\mu$ m  > 6.0 $\mu$ m	12 % - 5 % 2 % - 8 % 8% - 10%  TBD	Deuterium Arc Lamp Tungsten-Filament Quartz-Halogen Lamp  Blackbody Standards
Detector Response	200 nm - 250 nm 250 nm - 1.8 $\mu$ m 1.8 $\mu$ m - 20 $\mu$ m	7% 1% - 3% TBD	Comparison to Calibrated Standard Detectors
Reflectance	250 nm - 2.5 $\mu$ m	0.5 % - 2.0 % Typical	Comparison to Calibrated Reflectance Standards
Transmittance	200 nm - 2.5 $\mu$ m	0.1 % - 1.0 % Typical	Subtraction Method

# CALIBRATION LABORATORY PERFORMANCE

CONSECUTIVE FISCAL YEARS



NOTE: charted results include both calibrations and repairs.



**LYNDON B. JOHNSON SPACE CENTER  
MEASUREMENT STANDARDS AND CALIBRATION LABORATORY  
FISCAL YEAR 1992 METROLOGY PROGRAM  
STATUS REPORT**

**DAVID C. DITTMAR  
INSTITUTIONAL SAFETY AND QUALITY DIVISION  
PROCESS ENGINEERING BRANCH  
LYNDON B. JOHNSON SPACE CENTER  
HOUSTON, TEXAS**

**SIXTEENTH ANNUAL NASA METROLOGY AND CALIBRATION WORKSHOP  
HOSTED BY: NASA JET PROPULSION LABORATORY AND THE  
NATIONAL INSTITUTE OF STANDARDS TECHNOLOGY  
LOCATION: POTOMAC INN, ROCKVILLE, MARYLAND  
APRIL 19 - 22, 1993**





JOHNSON SPACE CENTER METROLOGY PROGRAM  
FY'92 STATUS REPORT

SUMMARY

The Johnson Space Center (JSC) metrology and calibration program is an evolving process. It has continued to experience change since its inception. Changes incorporated during FY'92 encompassed capability improvements, production increase requirements, increased metrology engineering activity, more emphasis on Total Quality Management principles, in addition to many others that affected the day to day operations.

One significant change worthy of mention at the start of this report is the completion of Phase I of the new JSC Metrology Facility. Phase I consisted of the construction of a 5,000 square feet building with environmental controls but no internal finishing (walls, doors, etc.). Phase II, to be completed during FY'93, will consist of completing the 5,000 square feet facility. Once Phase III, construction of a 7,000 square feet addition to the 5,000 square feet facility, is completed, toward the third quarter of FY'94, two-thirds of the JSC Measurement Standards and Calibration Laboratory (MSCL) operation will be housed in the new, specifically designed, metrology facility. Two to three more phases of construction will be necessary before the total MSCL will be located in the new facility; probably not before FY'96 or FY'97.

JSC MSCL metrology, calibration, and instrument repair activities during FY'92 are presented for review.

Specific items presented in this report are:

- \* A general review of the JSC Metrology Program,
- \* JSC/MSCL NASA and contractor staffing,
- \* Reliability analysis data,
- \* FY'92 production statistics,
- \* Standards and capability enhancement data, and
- \* JSC/MSCL Quality Assurance Program activity and results.

JSC METROLOGY PROGRAM

The Johnson Space Center metrology facilities are operated by SIMCO Electronics of Santa Clara, California. SIMCO is currently in the first year of a five year contract awarded by JSC to operate the JSC/MSCL facilities.

Responsibilities of the MSCL encompass providing calibration and repair services to all JSC and JSC contractor organizations, the Texas Air National Guard (TANG) at Ellington Field, the United States Coast Guard at Ellington Field, and the Federal Aviation Administration located in Houston, Texas.

Additionally, NASA Technical Management of the MSCL is tasked with oversight of the Crew and Thermal Systems Division (CTSD) Satellite Calibration Laboratory (SCL) operation; approving calibration procedures, surveying the operation, etc. The MSCL SCL in the JSC CTSD completed 1340 items during FY'92. CTSD SCL calibration status data are analyzed and used in the determination of the reliability of all JSC instrumentation. Of the 1340 items calibrated by the CTSD SCL 197 were received within calibration specifications requiring no adjustments, 335 were received within specifications but were adjusted for optimization, 336 were received outside of calibration specifications and were adjusted, 2 were received outside specifications and required repair prior to being adjusted within specifications, 16 received a LIMITED USE status, and 454 fell into an "OTHER" category; initial calibration, calibration after external repair, etc. Please note, the production of the CTSD SCL IS NOT included in the production and quality data included in the charts, graphs, and figures presented in this report.

MSCL production demands continued to increase during FY'92. The 24,867 items calibrated during FY'92 represented an increase of 11.4 percent over the previous high year, FY'91. This was accomplished while maintaining the FY'92 turnaround time (TAT) at 5.0 working days, the same TAT achieved during FY'91, even though the production demand increased. Further information concerning productivity measures is provided in charts and graphs accompanying this report.

The MSCL Internal Quality Assurance Program was converted to a Designated Verification Program during FY'92, at the start of the current five year contract with SIMCO Electronics. Metrology, being a 100 percent quality verification process, is augmented in the MSCL with an inspection process based on random selection of the technician, whose work is to be inspected, through his technician stamp number. A designated senior level technician in each laboratory section inspects the next item calibrated by the selected technician. Additionally, 100 percent of all calibration documentation is checked by each laboratory section supervisor. Also, impromptu inspections of standards and systems to be used in in-place operations are performed to assure correct status. All quality program results data are compiled, analyzed for trends, and reported to upper level management weekly, monthly, and tri-annually in contractually required reporting formats.

Only twenty-seven (27) meetings of the MSCL NASA/Contractor Management Committee were conducted during FY'92. An additional 109 action items were undertaken during these 27 meetings, bringing the total to 609 action items considered since inception of the committee. Only eight (8) of the original 609 actions remain open. This committee process continues to be the best means available for addressing the ever changing role of metrology at JSC and within the NASA Agency.

MSCL personnel were instrumental in the development of a metrication presentation for use in fostering acceptance of "GOING METRIC" in all aspects of everyday operations, at home and at work. Once the presentation was seen by influential personnel at JSC the decision was made to prepare a video tape for use in educating all of JSC in metrication. A major portion of the MSCL presentation was used in making the JSC Metrication Video.

## CALIBRATION PROGRAM ANALYSIS

The MSCL is under the direction of the JSC Safety, Reliability, and Quality Assurance Office; Institutional Safety and Quality Division; Process Engineering Branch. The NASA Technical Manager of the MSCL operations is David C. Dittmar. The NASA Technical Monitor of the MSCL is Jose M. Olivarez. Currently, thirty-eight (38) contractor personnel maintain and operate the MSCL. MSCL staffing, both contractor and NASA, are presented in figure 1.

## WORK ANALYSIS

An analysis of the work performed by the MSCL in support of JSC and JSC Contractor organizations during FY'92 is presented in the next nineteen (19) figures.

Figures 2a thru 2e presents, in tabular form, the current JSC MSCL instrument inventory in the MSCL Metrology Information Management System (MIMS) database. The data in the tables are arranged alphabetically by instrument nomenclature. The nomenclatures used in the tables correspond to the JSC MSCL Instrument Codes (not listed in the tables) used in the MSCL calibration operation. The following data is presented in the tables for each instrument nomenclature:

- o inventory of items per table line item,
- o total hours expended calibrating per table line item,
- o average hours per table line item, and
- o quantity breakout per line item of the calibration status (i.e., received in tolerance, received out of tolerance and adjusted, limited calibration performed, or rejected).

The above four calibration status situations are quantified for the total inventory on figure 2e.

Figure 3 presents the calibration and repair history of the MSCL for FY'88 thru FY'92. The data in Figure 3 illustrates the record setting productivity achievements of the MSCL during FY'92. The specific records established were:

- o Physical/Mechanical Calibration Laboratory (PMCL) calibration actions completed during FY'92 exceeded the previous record set in FY'91 by 18 percent. This productivity (15,888 items) exceeded the average yearly production of the previous four years (11,474 items per year) by 38.5 percent.
- o Priority service requests were less during FY'92; however, they still exceeded the average of the past four years (694) by 28.1 percent.
- o In situ services during FY'92 experienced a dramatic increase. More JSC MSCL customers are requiring calibration of delicate and/or large systems in-place rather than remove them from permanent installations and transport them to the MSCL facilities for calibration. In situ calibration actions increased by 19.7 percent over the previous high year, FY'90. Likewise, in situ service increased by 33.9 percent over the average of the previous four years.

- o Electrical/Electronic Calibration and Repair Laboratory (EEC&RL) calibration actions exceeded the previous high year (FY'91) by 1.3 percent and exceeded the average of the previous four years by 1.5 percent. This was accomplished while experiencing a reduction of personnel and facing ever more complex calibration requirements.
- o Other data presented in tabular form in figure 3 are further illustrated in the following charts and graphs.

Figure 4 presents graphically a comparison of FY'92 monthly production statistics; Items Received, Items Calibrated, Hours per Item and Turn Around Time (TAT) for each month of the fiscal year are illustrated in comparison format. The highest amount of items received (3524) and items calibrated (3438) in any one month of the year occurred during May 1992.

Figure 5 presents in bar graph format the annual fiscal year production of the MSCL during the period of FY'85 thru FY'92. The production during FY'92 of 24,867 items exceeded the next highest year, FY'91, by 11.4 percent. FY'92's production exceeded the average production achieved over the previous seven years by 30.9 percent.

Figure 6 presents an overview of the items calibrated, hours per item and turn around time categories over the previous six fiscal years, FY'87 thru FY'92. As noted in other charts, the production has steadily increased while the turn around time has been held to an average of 5.0 working days the last three FY's. The hours per item has steadily decreased since FY'89 reaching a low of 1.6 during FY'92.

Figure 7 is provided to illustrate the productivity of the MSCL repair function over the last nine fiscal years. The repair actions completed during FY'92 decreased significantly below those accomplished during the previous eight years. FY'92 completions were 28.8 percent below the highest year (FY'84) and 7.5 percent below the previously low year (FY'91). Even though the productivity appears to be decreasing, the fact is that the backlog of items awaiting repair was maintained at the lowest level of any fiscal year. Additionally, the repair technicians were utilized at different times during the year to perform calibration operations; helping maintain control of the backlog of items awaiting calibration.

Figure 8 depicts the output of the MSCL Automatic Calibration Systems (ACS) over the past twelve fiscal years. FY'92's ACS production increased slightly over previous years, approximately 0.4 percent over the next highest production year (FY'90). Procedures that are being written for use in calibrating automatically are predominantly for one of a kind inventory items. The multiple inventory items (one procedure used to calibrate from 100 to 200 items) have all been automated. Production increases are rather flat because of this situation. Duplicate ACS units will have to be purchased and placed into operation if we hope to see a continued increase in this production area.

A testament to the efficiency of the MSCL is presented in an overview look at the TAT. Figure 9 depicts an isolated picture of the TAT achieved over the last eight fiscal years. The TAT for four of the eight years was 5.0 working days. The average for the eight years was 5.4 working days. The 5.0 TAT was achieved and held while the work load increased, as stated in previous paragraphs, and the staffing level was decreased.

Figure 10 presents graphically the condition of equipment when it was submitted for calibration during FY'92. Also, a measure of the responsiveness of JSC MSCL customers to the JSC MSCL Recall Program is presented. Figure 10 summarizes the data presented in Figures 2a thru 2e.

Figure 11 presents, in tabular form, the JSC MSCL Recall Program Instrument Inventory activity during FY'92.

#### JSC MSCL REFERENCE STANDARDS ENHANCEMENT

The MSCL is charged with the responsibility to maintain the traceability of all measurements performed at JSC to national standards maintained by the National Institute of Standards and Technology (NIST), intrinsic standards, or other recognized reference standards. Approximately \$90K was expended in that effort during FY'92. Figure 12 lists the procurement actions that were undertaken to maintain current with the state-of-the-art in reference standards maintenance activity.

#### GENERAL LABORATORY CAPABILITY ENHANCEMENT

The Secondary Calibration Laboratories, both Physical/Mechanical and Electrical/Electronic must maintain their status current with the state-of-the-art in measurement capability in order to meet the changing requirements of the JSC MSCL customer. Figures 13 and 14 list the actions undertaken in pursuit of excellence in this category by the two Secondary Calibration Laboratories during FY'92.

#### CALIBRATION PROCEDURE/SOFTWARE DEVELOPMENT

Metrology principles and practices, not to mention contractual obligations, dictate that every calibration action undertaken by the MSCL must be covered by an individual, unique, calibration procedure. In consideration of this requirement it is understandable that procedure development is a vital part of the MSCL operational process. Figures 15 and 16 list calibration procedure development activity during FY'92 and an accumulation of this type of activity since inception of the MSCL operation. Figure 15 lists manual calibration procedure development activity, while Figure 16 lists automatic calibration procedure development activity.

### CERTIFICATION OF REFERENCE STANDARDS

Along with procurement of the newest state-of-the-art standards, maintaining current certification of the existing standards is a priority of any reference standards laboratory operation. Figures 17 and 18 lists the activity that was undertaken in this certification effort by the JSC MSCL Reference Standards Laboratory during FY'92.

Figure 19 lists the reference standard certifications that are planned to be obtained during FY'93 by the JSC MSCL Reference Standards Laboratory.

### JSC MSCL QUALITY ASSURANCE PROGRAM ACTIVITY

The MSCL Quality Assurance Program underwent a philosophical change at the start of the current contract. The method of performing inspections and the rationale was explained earlier in this report. Since the scope of the program did not change, the results of the program continue to be maintained and reported in the same manner and format. Figure 20 presents, in tabular form, the results of the MSCL Quality Assurance Program during FY'92.

THE FORGOING JSC MSCL METROLOGY PROGRAM OVERVIEW AND THE FOLLOWING CHARTS, GRAPHS, AND TABLES ARE PRESENTED FOR YOUR REVIEW AND INFORMATION.

# JSC/MSCL STAFFING FY - '92

## SIMCO ELECTRONICS INC.

### NASA

TECHNICAL MANAGER	1	MANAGER	1
TECHNICAL MONITOR	1	ENGINEER/SUPERVISOR	3
		SUPERVISORS	3
		TECHNICANS	23
		PROGRAMMER/SUPERVISOR	1
		LAN ADMINISTRATOR	1
		CLERICAL	<u>6</u>
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FIGURE 1

RELIABILITY ANALYSIS:  
JSC MEASUREMENT STANDARDS AND CALIBRATION LABORATORY  
FISCAL YEAR 1992

EQUIPMENT DESCRIPTION	ITEMS	HOURS	HRS/ITEM	REC'D	REC'D	OUT OF TOL	LIMITED	REJECTED
				IN-TOL	REP/ADJ.		CAL'D	
ACCELEROMETERS, VIBRATION	1836.0	1265.3	0.7	21.0	2.0		1783.0	27.0
ACCELEROMETERS, LINEAR	8.0	8.0	1.0	0.0	0.0		8.0	0.0
ACCELEROMETER, VELOCITY	5.0	5.0	1.0	0.0	0.0		5.0	0.0
ACCELERATION, VIBRATING DEVICES	6.0	17.0	2.8	2.0	0.0		3.0	1.0
ACOUSTICS, MICROPHONES	81.0	98.3	1.2	5.0	0.0		76.0	0.0
ACOUSTICS, SOUND LEVEL METERS	25.0	89.5	3.6	19.0	0.0		5.0	1.0
ACOUSTICS, SOUND PRESS. CALIBRATOR	21.0	37.0	1.8	15.0	1.0		3.0	2.0
AMPLIFIER, POWER	133.0	93.5	0.7	22.0	104.0		4.0	2.0
AMPLIFIER, AC(DC) AUDIO	556.0	574.3	1.0	238.0	274.0		32.0	12.0
AMPLIFIER RF/MICROWAVE	5.0	10.5	2.1	4.0	0.0		0.0	1.0
ANALYZER GAS (AT)	1.0	1.5	1.5	1.0	0.0		0.0	0.0
ANALYZER, GAS (AY)	87.0	101.2	1.2	67.0	10.0		8.0	2.0
ANALYZER, LIQUID	4.0	6.1	1.5	3.0	0.0		0.0	1.0
ANALYZER, SERVO	2.0	6.0	3.0	0.0	0.0		2.0	0.0
ANALYZER, SPECTRUM	87.0	985.2	11.3	47.0	10.0		20.0	10.0
ANALYZER, DISTORTION	101.0	404.3	4.0	77.0	7.0		13.0	3.0
ANALYZER, NETWORK	3.0	10.5	3.5	2.0	0.0		1.0	0.0
ANALYZER, WAVEFORM	43.0	288.8	6.7	27.0	3.0		10.0	3.0
ATTENUATOR, AUDIO/VIDEO	13.0	17.2	1.3	10.0	0.0		3.0	0.0
ATTENUATOR, RF/MICROWAVE	174.0	169.1	1.0	130.0	1.0		42.0	1.0
ATTENUATION, STDS/MEAS. DEVICES	5.0	21.2	4.2	3.0	1.0		1.0	0.0
BRIDGE, CAPACITANCE	6.0	15.7	2.6	3.0	0.0		2.0	1.0
BRIDGE, INDUCTANCE	1.0	6.5	6.5	0.0	0.0		1.0	0.0
BRIDGE, IMPEDANCE	8.0	22.5	2.8	3.0	2.0		2.0	1.0
BRIDGE, RESISTANCE	15.0	70.5	4.7	11.0	1.0		3.0	0.0
BRIDGE, RLC	4.0	14.5	3.6	3.0	0.0		1.0	0.0
BRIDGE, R.F.	1.0	14.0	14.0	0.0	0.0		1.0	0.0
CALIBRATOR, METER	67.0	204.2	3.0	54.0	8.0		3.0	2.0
CAPACITOR, DECADE	13.0	25.5	2.0	9.0	0.0		4.0	0.0
CAPACITOR, STANDARD	36.0	25.3	0.7	31.0	0.0		4.0	0.0
CONTROLLER	2.0	28.0	14.0	2.0	0.0		0.0	0.0
CONVERTER, AC/DC THERMAL	9.0	16.4	1.8	9.0	0.0		0.0	0.0
CONVERTER, FREQUENCY	68.0	49.0	0.7	63.0	4.0		0.0	1.0
COUNTER, FREQUENCY/PERIOD	410.0	360.9	0.9	343.0	28.0		34.0	4.0
COUNTER (TIME/STOPWATCH)	12.0	11.5	1.0	5.0	1.0		6.0	0.0
COUPLER, DIRECTIONAL COAXIAL	36.0	57.3	1.6	24.0	0.0		12.0	0.0
DIMENSIONAL, CALIPERS (ALL TYPES)	205.0	184.3	0.9	189.0	0.0		8.0	5.0
DIMENSIONAL, CATHETERMETER	1.0	3.0	3.0	1.0	0.0		0.0	0.0
DIMENSIONAL, CYL/MACHINE SQ.	3.0	5.5	1.8	3.0	0.0		0.0	0.0
DIMENSIONAL, DIAL INDICATORS	167.0	153.8	0.9	164.0	0.0		2.0	1.0
DIMENSIONAL, GRANITE STDS.	7.0	9.5	1.4	7.0	0.0		0.0	0.0
DIMENSIONAL, I GAGE BLK COMPARITORS	2.0	4.5	2.3	2.0	0.0		0.0	0.0
DIMENSIONAL, GAGE BLK STANDARD	10.0	43.0	4.3	9.0	0.0		1.0	0.0
DIMENSIONAL, GAGE BLK WORKING	22.0	136.0	6.2	22.0	0.0		0.0	0.0
DIMENSIONAL, HEIGHT GAGE(ELE)	24.0	38.7	1.6	21.0	1.0		2.0	0.0
DIMENSIONAL, HEIGHT GAGE(MECH)	21.0	27.7	1.3	21.0	0.0		0.0	0.0
DIMENSIONAL, LEVELS	26.0	48.5	1.9	19.0	5.0		1.0	1.0
DIMENSIONAL, LINEAR TRANSDUCER	114.0	126.5	1.1	73.0	0.0		34.0	7.0
DIMENSIONAL, MEAS. MACHINE (PREC)	5.0	14.0	2.8	4.0	0.0		0.0	0.0
DIMENSIONAL, MEASURING WIRES	2.0	7.0	3.5	2.0	0.0		0.0	0.0
DIMENSIONAL, MICROMETERS	461.0	464.4	1.0	428.0	10.0		16.0	5.0
DIMENSIONAL, PARALLEL BARS	8.0	25.0	3.1	5.0	0.0		3.0	0.0

FIGURE 2a



RELIABILITY ANALYSIS:  
ISC MEASUREMENT STANDARDS AND CALIBRATION LABORATORY  
SCAL YEAR 1992

EQUIPMENT DESCRIPTION	ITEMS	HOURS	HRS/ITEM	REC'D	REC'D	OUT OF TOL	LIMITED	REJECTED
				IN-TOL	REP/ADJ.		CAL'D	
DIMENSIONAL PLUG GAGES	75.0	142.0	1.9	59.0	0.0		11.0	5.0
DIMENSIONAL THREAD PLUGS	104.0	140.0	1.3	103.0	0.0		0.0	1.0
DIMENSIONAL PROTRACTERS	37.0	38.3	1.0	31.0	2.0		3.0	1.0
DIMENSIONAL RING GAGES	50.0	85.0	1.7	49.0	1.0		0.0	0.0
DIMENSIONAL THREAD RING GAGES	157.0	159.5	1.0	145.0	12.0		0.0	0.0
DIMENSIONAL RODS, LENGTH, MEAS.	20.0	35.0	1.8	20.0	0.0		0.0	0.0
FLOW INDICATOR/CONTROLLER (EC)	8.0	21.0	2.6	2.0	0.0		5.0	0.0
FLOW INDICATOR/CONTROLLER (ED)	9.0	15.6	1.7	3.0	0.0		4.0	2.0
DIMENSIONAL SCALES/STRAIGHT EDGES	7.0	15.5	2.2	7.0	0.0		0.0	0.0
DIMENSIONAL SINE PLATES AND BARS	4.0	7.0	1.8	4.0	0.0		0.0	0.0
DIMENSIONAL SURFACE PLATES	9.0	44.0	4.9	9.0	0.0		0.0	0.0
FLOW TRANSDUCER	50.0	97.2	1.9	12.0	4.0		27.0	3.0
DIMENSIONAL V BLOCKS	2.0	4.0	2.0	2.0	0.0		0.0	0.0
FLOW SIGNAL CONDITIONER	7.0	2.5	0.4	0.0	0.0		7.0	0.0
DETECTOR/DEMODO, NULL, AC/DC, RF	11.0	16.4	1.5	9.0	0.0		2.0	0.0
FLOW VELOCITY INDICATOR/CONTROLLER-DIVIDER, VOLTAGE	8.0	14.6	1.8	2.0	0.0		2.0	4.0
FLOW VELOCITY INDICATOR/CONTROLLER-ENVIRONMENTAL, MERCURY DETECTORS	15.0	30.6	2.0	15.0	0.0		0.0	0.0
	9.0	27.5	3.1	2.0	0.0		5.0	2.0
ENVIRONMENTAL, MERCURY DETECTORS	3.0	2.0	0.7	1.0	1.0		0.0	0.0
FILTER, BAND, HIGH/LOW PASS	18.0	100.5	5.6	13.0	1.0		4.0	0.0
FLOW, GAS HOT WIRE	68.0	128.1	1.9	10.0	1.0		47.0	6.0
FLOW, LAMINAR STANDARDS	66.0	168.0	2.5	40.0	0.0		25.0	1.0
FORCE, TORQUE TRANSDUCER	3.0	5.5	1.8	1.0	0.0		2.0	0.0
FLOW, ORFICE	9.0	52.5	5.8	5.0	1.0		3.0	0.0
FLOW, POSITIVE DISPLACEMENT	12.0	196.9	16.4	5.0	2.0		4.0	0.0
FLOW, ROTOMETER (GAS)	371.0	693.3	1.9	58.0	0.0		256.0	11.0
FLOW, ROTOMETER (LIQUID)	59.0	101.2	1.7	22.0	0.0		32.0	4.0
FLOW, TURBINE (LIQUID)	146.0	135.2	0.9	79.0	0.0		53.0	13.0
FLOW, TURBINE (GAS)	6.0	9.5	1.6	2.0	0.0		3.0	1.0
FORCE, DYNAMOMETERS	22.0	29.5	1.3	9.0	0.0		12.0	1.0
FORCE, GAGES	139.0	165.9	1.2	96.0	1.0		38.0	4.0
FORCE, HYDRA SETS	3.0	4.6	1.5	3.0	0.0		0.0	0.0
FORCE, LOAD CELLS	331.0	679.9	2.1	99.0	0.0		229.0	3.0
FIBER OPTIC LIGHT WAVE SOURCE	2.0	2.0	1.0	0.0	0.0		2.0	0.0
FORCE, MACHINE	7.0	72.5	10.4	3.0	0.0		4.0	0.0
FIBER OPTIC TIME DOMAIN REFLECTOMETER	1.0	5.0	5.0	0.0	0.0		1.0	0.0
FIBER OPTIC POWER METER	21.0	29.0	1.4	4.0	0.0		16.0	1.0
FORCE, STRAIN INDICATORS	41.0	59.2	1.4	33.0	1.0		4.0	3.0
ALTIMETER	1.0	2.0	2.0	1.0	0.0		0.0	0.0
FORCE, TORQUE WRENCHES	925.0	835.9	0.9	764.0	53.0		75.0	33.0
FORCE, TORQUE WRENCH TESTERS	29.0	41.0	1.4	23.0	1.0		3.0	1.0
FORCE, WEIGHING SYSTEMS	5.0	12.5	2.5	4.0	0.0		1.0	0.0
GENERATOR, FUNCTION	253.0	911.7	3.6	201.0	18.0		26.0	5.0
GENERATOR, FREQ. (RF/MICROWAVE)	176.0	872.8	5.0	99.0	28.0		41.0	5.0
GENERATOR, FREQ. (AUDIO/VIDEO)	100.0	243.2	2.4	78.0	7.0		13.0	2.0
GENERATOR, NOISE	17.0	46.9	2.8	16.0	1.0		0.0	0.0
GENERATOR, PULSE	83.0	291.9	3.5	65.0	6.0		11.0	1.0
GENERATOR, VIDEO/TELEVISION	68.0	543.9	8.0	57.0	8.0		3.0	0.0
GENERATOR, SWEEP	17.0	136.0	8.0	7.0	3.0		5.0	2.0
HUMIDITY, DEW POINT HYGROMETER	95.0	221.4	2.3	9.0	0.0		73.0	7.0
HYDROMETER	12.0	17.0	1.4	7.0	1.0		3.0	1.0
HUMIDITY, INDICATOR (RH)	44.0	83.2	1.9	6.0	0.0		33.0	2.0

FIGURE 2b

RELIABILITY ANALYSIS:  
JSC MEASUREMENT STANDARDS AND CALIBRATION LABORATORY  
FISCAL YEAR 1992

EQUIPMENT DESCRIPTION	ITEMS	HOURS	HRS/ITEM	REC'D	REC'D	LIMITED	REJECTED
				IN-TOL	OUT OF TOL REP/ADJ.	CAL'D	
INDUCTOR, DECADE	2.0	5.0	2.5	1.0	0.0	1.0	0.0
INDUCTOR, STD.	10.0	4.0	0.4	0.0	0.0	10.0	0.0
LIGHT, LAMPS STANDARDS	2.0	20.0	10.0	1.0	0.0	1.0	0.0
LIGHT WAVE, WAVELENGTH STANDARD	13.0	56.0	4.3	13.0	0.0	0.0	0.0
LIGHT, METERS	60.0	358.3	6.0	33.0	9.0	13.0	3.0
LIGHT, TRANSDUCER	4.0	32.0	8.0	4.0	0.0	0.0	0.0
MASS, BALANCES (PRECISION/WORKING)	128.0	244.1	1.9	101.0	8.0	10.0	4.0
MASS, SCALES (PLATFORM)	64.0	124.9	2.0	51.0	3.0	6.0	3.0
MASS, WEIGHTS STD	16.0	26.5	1.7	12.0	0.0	4.0	0.0
MASS, WEIGHTS (WORKING)	199.0	224.0	1.1	187.0	10.0	2.0	0.0
METER, ELECTROMETER	2.0	4.0	2.0	1.0	0.0	0.0	1.0
METER, FREQUENCY	8.0	8.4	1.1	5.0	1.0	2.0	0.0
METER, GAUSS	5.0	6.0	1.2	2.0	0.0	3.0	0.0
METER, I/C	67.0	139.7	2.1	11.0	5.0	51.0	0.0
METER, OHM	78.0	82.5	1.1	59.0	2.0	14.0	2.0
METER, MILLIOVOLT RF	19.0	57.5	3.0	12.0	3.0	1.0	3.0
METER, MODULATION	26.0	118.6	4.6	16.0	5.0	4.0	1.0
METER, MULTIMETERS	117.0	142.5	1.2	71.0	16.0	20.0	10.0
METER, PANEL AC CURRENT	4.0	4.6	1.2	3.0	0.0	0.0	1.0
METER, PANEL AC VOLT	4.0	4.1	1.0	3.0	0.0	0.0	1.0
METER PANEL VAR	18.0	11.1	0.6	17.0	0.0	1.0	0.0
METER, PANEL DC CURRENT	24.0	18.6	0.8	18.0	0.0	5.0	1.0
METER PANEL WATT	3.0	1.6	0.5	3.0	0.0	0.0	0.0
METER, PANEL DC VOLT	42.0	29.1	0.7	40.0	2.0	0.0	0.0
METER, PHASE	27.0	89.5	3.3	17.0	1.0	8.0	1.0
METER, PORTABLE AC CURRENT	36.0	39.1	1.1	24.0	0.0	9.0	3.0
METER, PORTABLE AC VOLT	5.0	7.0	1.4	5.0	0.0	0.0	0.0
METER, PORTABLE DC CURRENT	28.0	19.5	0.7	27.0	0.0	1.0	0.0
METER, PORTABLE DC VOLT	9.0	10.7	1.2	8.0	0.0	1.0	0.0
METER, POWER BELOW 10MHZ	17.0	18.6	1.1	15.0	0.0	0.0	2.0
METER, POWER ABOVE 10MHZ	87.0	168.5	1.9	68.0	4.0	15.0	0.0
METER, Q METER	2.0	3.0	1.5	2.0	0.0	0.0	0.0
METER, THERMAL TRANSFER (REG/STD)	7.0	45.2	6.5	7.0	0.0	0.0	0.0
METER, DIFFERENTIAL	43.0	102.0	2.4	29.0	7.0	1.0	6.0
METER, DIGITAL	579.0	638.5	1.1	402.0	107.0	60.0	9.0
METER, DIGITAL PREC. (REC. MFG. CODE)	540.0	659.8	1.2	370.0	101.0	64.0	5.0
METER, DIGITAL 12 MONTH CYCLE	610.0	508.3	0.8	503.0	64.0	32.0	9.0
METER, VTVM/VTM (BATTERY TYPE INC.)	229.0	269.8	1.2	168.0	39.0	14.0	7.0
METER, WATT (4 TERMINAL)	70.0	76.7	1.1	50.0	18.0	1.0	1.0
METER, WOW AND FLUTTER	9.0	67.9	7.5	4.0	0.0	4.0	0.0
MIXER/MODULATOR	1.0	1.5	1.5	1.0	0.0	0.0	0.0
OPTICAL, COLLIMATORS, AUTO	2.0	6.0	3.0	2.0	0.0	0.0	0.0
OPTICAL, COLLIMATORS, RANGE	3.0	5.0	1.7	3.0	0.0	0.0	0.0
OPTICAL, CUBES AND POLYGONS	1.0	2.0	2.0	1.0	0.0	0.0	0.0
OPTICAL, INDEX TABLES	6.0	6.5	1.1	6.0	0.0	0.0	0.0
OPTICAL, INTERFEROMETER (POINTING)	5.0	5.0	1.0	3.0	0.0	2.0	0.0
OPTICAL, LEVELS	6.0	8.0	1.3	6.0	0.0	0.0	0.0
OPTICAL, PRISMS (ALL TYPES)	1.0	2.0	2.0	1.0	0.0	0.0	0.0
OPTICAL, TELESCOPES-MICROMETERS	7.0	16.0	2.3	7.0	0.0	0.0	0.0
OPTICAL, THEODOLITES (ALL TYPES)	2.0	6.0	3.0	2.0	0.0	0.0	0.0
OPTICAL, TRANSIT (ALL TYPES)	28.0	61.0	2.2	28.0	0.0	0.0	0.0
CALIB. LABORATORY STANDARD	18.0	59.4	3.3	15.0	0.0	3.0	0.0

FIGURE 2c

RELIABILITY ANALYSIS:  
NIST MEASUREMENT STANDARDS AND CALIBRATION LABORATORY  
FISCAL YEAR 1992

EQUIPMENT DESCRIPTION	ITEMS	HOURS	HRS/ITEM	REC'D	REC'D	LIMITED	REJECTED
				IN-TOL	OUT OF TOL REP/ADJ.	CAL'D	
OSCILLOSCOPES	887.0	1975.1	2.2	745.0	83.0	46.0	12.0
PHASE SHIFTER	2.0	12.0	6.0	1.0	0.0	1.0	0.0
PHYSICAL, CRIMP TOOLS	1419.0	786.2	0.6	50.0	0.0	1338.0	26.0
PHYSICAL, HARDNESS TESTERS	20.0	24.0	1.2	13.0	0.0	7.0	0.0
PHYSICAL, WIRE STRIPPER	133.0	102.0	0.8	97.0	0.0	36.0	0.0
PHYSICAL, PARTICLE COUNTERS	34.0	98.0	2.9	33.0	0.0	1.0	0.0
MEDICAL SIMULATION/MONITOR	2.0	11.5	5.8	1.0	1.0	0.0	0.0
PHYSICAL, TACHOMETER	4.0	4.5	1.1	3.0	0.0	1.0	0.0
PHYSICAL, PH METER	4.0	7.0	1.8	1.0	0.0	2.0	1.0
PLUG-IN, COUNTER	28.0	22.2	0.8	27.0	0.0	1.0	0.0
PLUG-IN, DIGITAL	3.0	2.0	0.7	2.0	0.0	0.0	1.0
PLUG-IN, GENERATOR	2.0	5.5	2.8	2.0	0.0	0.0	0.0
PLUG-IN, OSCILLOSCOPES	772.0	1068.3	1.4	682.0	65.0	20.0	4.0
PLUG-IN, RF PWR MTR CALORIMETER	124.0	114.8	0.9	94.0	1.0	23.0	4.0
PLUG-IN, OTHER	7.0	7.6	1.1	6.0	0.0	0.0	0.0
POTENTIOMETERS	2.0	17.0	8.5	2.0	0.0	0.0	0.0
POWER SUPPLIES, AC	6.0	16.5	2.8	4.0	0.0	1.0	1.0
POWER SUPPLIES, DC	127.0	286.4	2.3	92.0	4.0	24.0	3.0
PRESSURE, DEADWEIGHT TESTERS	4.0	10.0	2.5	4.0	0.0	0.0	0.0
PRESSURE, GAGES (PSIG, PSIA, PSID)	1531.0	2723.2	1.8	1022.0	146.0	285.0	44.0
PRESSURE, RELIEF VALVES/SWITCHES	8.0	11.5	1.4	6.0	2.0	0.0	0.0
PRESSURE SIGNAL CONDITIONER	5.0	12.5	2.5	1.0	3.0	0.0	1.0
PRESSURE, TRANSD. (PSIG, PSIA, PSID)	434.0	832.1	1.9	202.0	18.0	139.0	10.0
PRESSURE, STDs (LIQ. IN GLASS)	12.0	35.6	3.0	10.0	0.0	2.0	0.0
STANDARDS, VOLTS, AC/DC	236.0	684.6	2.9	157.0	44.0	30.0	5.0
ALTIMETER	7.0	24.0	3.4	6.0	1.0	0.0	0.0
PRESSURE INDICATOR/CONTROLLER	4.0	23.5	5.9	0.0	0.0	3.0	1.0
PROBE, CURRENT AMPLIFIER	7.0	7.2	1.0	7.0	0.0	0.0	0.0
PROBES (ALL TYPES)	95.0	162.3	1.7	64.0	3.0	24.0	4.0
RADAR/RADIO TEST SET	21.0	140.9	6.7	8.0	6.0	5.0	2.0
RATIO DEVICE	4.0	15.0	3.8	4.0	0.0	0.0	0.0
RECORDERS	37.0	99.3	2.7	23.0	9.0	4.0	1.0
RESISTOR, DECADE	91.0	102.9	1.1	64.0	3.0	24.0	0.0
RESISTOR, STANDARD/TERMINATION	156.0	189.8	1.2	131.0	1.0	24.0	0.0
TERMINATION (RF/MICROWAVE)	1.0	1.0	1.0	1.0	0.0	0.0	0.0
RESOLVERS, SYNCHRO STANDARD	3.0	10.0	3.3	2.0	0.0	1.0	0.0
SHUNTS, AC/DC	330.0	152.5	0.5	143.0	22.0	164.0	1.0
STANDARDS, CURRENT	5.0	16.5	3.3	3.0	0.0	2.0	0.0
STANDARDS, FREQUENCY	4.0	3.0	0.8	4.0	0.0	0.0	0.0
STROBE SCOPE	8.0	8.5	1.1	5.0	2.0	1.0	0.0
TEMPERATURE, RECORDER	27.0	47.0	1.7	18.0	0.0	9.0	0.0
TEMP., CONTROLLERS/RECORDERS	69.0	111.0	1.6	28.0	4.0	32.0	5.0
TEMPERATURE, TRANSDUCER	21.0	17.0	0.8	18.0	1.0	2.0	0.0
TEMPERATURE, TC SIMULATOR/CALIBRATOR	8.0	13.3	1.7	7.0	0.0	0.0	0.0
TEMP., GAGES	18.0	38.0	2.1	10.0	0.0	4.0	4.0
TEMP./HUMIDITY(RH) RECORDERS	131.0	252.9	1.9	15.0	0.0	114.0	2.0
TEMP., INDICATORS	75.0	128.4	1.7	36.0	8.0	25.0	4.0
TEMP., JUNCTION REFERENCE BOX	51.0	62.4	1.2	44.0	0.0	4.0	3.0
TEMP., METER, DIGITAL	153.0	242.1	1.6	117.0	7.0	21.0	4.0
TEMP., PLAT. RES. THERMOMETER	80.0	108.3	1.4	20.0	0.0	56.0	4.0
TEMP., RADIOMETER/PYROHELIOMETER	2.0	2.0	1.0	2.0	0.0	0.0	0.0
TEMP., THERMOCOUPLES	99.0	104.6	1.1	22.0	1.0	72.0	1.0

FIGURE 2d

RELIABILITY ANALYSIS:  
JSC MEASUREMENT STANDARDS AND CALIBRATION LABORATORY  
FISCAL YEAR 1992

<u>EQUIPMENT DESCRIPTION</u>	<u>ITEMS</u>	<u>HOURS</u>	<u>HRS/ITEM</u>	<u>REC'D</u>	<u>REC'D</u>	<u>LIMITED</u>	<u>REJECTED</u>
				<u>IN-TOL</u>	<u>OUT OF TOL</u> <u>REP/ADJ.</u>	<u>CAL'D</u>	
TEMP., THERMOMETERS	91.0	111.5	1.2	45.0	2.0	43.0	1.0
TEMPERATURE, SWITCH	2.0	4.0	2.0	0.0	0.0	2.0	0.0
TELEVISION MONITOR	92.0	608.5	6.6	67.0	21.0	4.0	0.0
TEMPERATURE, THERMISTOR	64.0	79.7	1.2	3.0	1.0	57.0	0.0
TEMP., TRANSDUCERS	2.0	5.0	2.5	0.0	1.0	1.0	0.0
TEST SET	9.0	42.0	4.7	5.0	0.0	1.0	1.0
TEST SET (6 MO.)	58.0	270.3	4.7	21.0	5.0	28.0	3.0
TIME DOMAIN REFLECTOMETER	13.0	60.5	4.7	10.0	1.0	0.0	2.0
TESTER, HIGH POTENTIAL	19.0	28.2	1.5	17.0	1.0	1.0	0.0
TESTER, TRANSISTOR, TUBE, DIODE	5.0	11.0	2.2	3.0	1.0	1.0	0.0
TEST SET (12 MO.)	88.0	247.8	2.8	36.0	4.0	23.0	8.0
TESTER, TRANSMISSION LINE	40.0	135.5	3.4	35.0	2.0	1.0	2.0
TRANSFORMER, CURRENT	123.0	101.0	0.8	66.0	3.0	54.0	0.0
TRANSFORMER, VOLTAGE	5.0	6.5	1.3	5.0	0.0	0.0	0.0
VACUUM INDICATOR/CONTROLLER	1.0	2.0	2.0	1.0	0.0	0.0	0.0
VACUUM, CAPACITANCE MANOMETER	62.0	180.2	2.9	19.0	6.0	34.0	3.0
VAC., GAGE CONTROLLER	104.0	282.1	2.7	40.0	3.0	52.0	7.0
VAC., ION TUBES	26.0	77.0	3.0	19.0	0.0	5.0	2.0
VAC., T/C TUBES	60.0	106.7	1.8	15.0	0.0	34.0	11.0
VAC., LEAK DETECTOR	2.0	1.0	0.5	0.0	0.0	1.0	0.0
VACUUM, STANDARD	2.0	8.0	4.0	0.0	0.0	2.0	0.0
VECTORSCOPE	8.0	49.0	6.1	7.0	1.0	0.0	0.0
WATT TRANSDUCER, LOW FREQUENCY	7.0	12.5	1.8	5.0	2.0	0.0	0.0
<hr/>							
CATEGORY TOTALS	20186.0	32227.2		11433.0	1520.0	6502.0	480.0
<hr/>							
AVERAGE HOURS PER ITEM		1.6 HOURS/ITEM					
PERCENT RECEIVED IN TOLERANCE		56.6 PERCENT					
PERCENT REC'D O-O-T REP. AND/OR ADJ'D		7.5 PERCENT					
PERCENT CLASSIFIED AS LIMITED CALIBRATION		32.2 PERCENT					
PERCENT REJECTED		2.4 PERCENT					
PERCENT ALL OTHER CLASSIFICATIONS		1.3 PERCENT					

FIGURE 2e

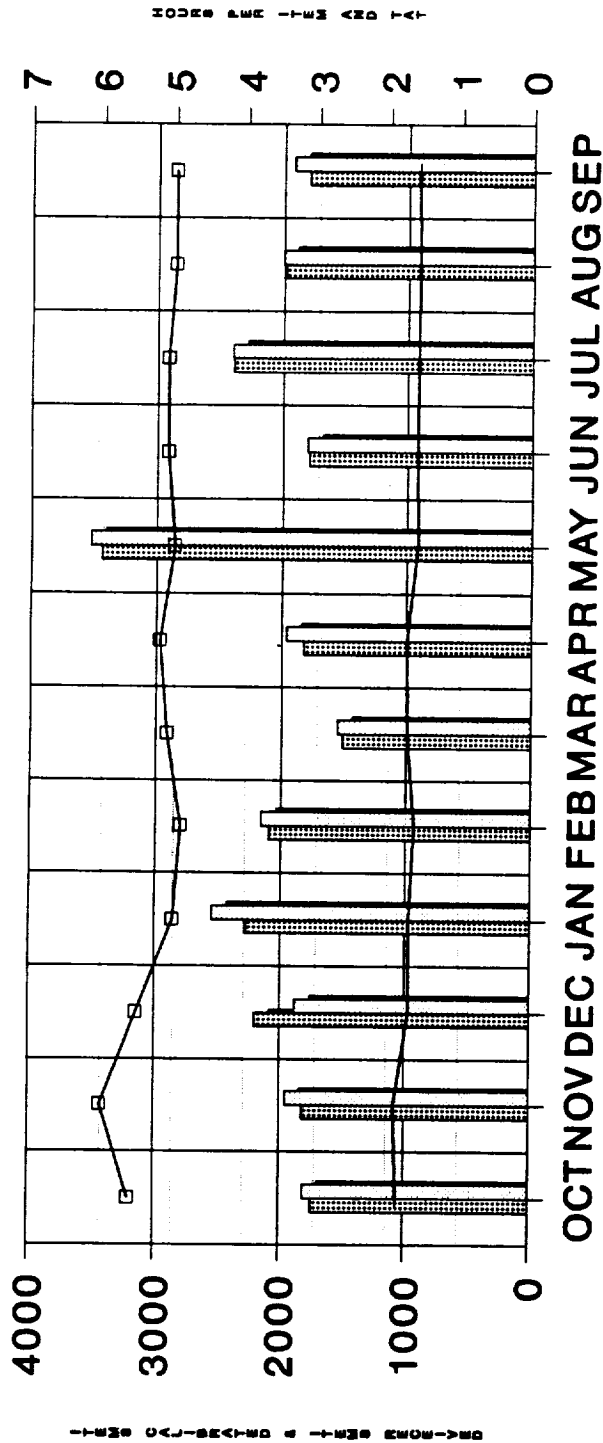
## CALIBRATION/REPAIR ACTIONS

	<u>FY88</u>	<u>FY89</u>	<u>FY90</u>	<u>FY91</u>	<u>FY92</u>
ELECTRICAL/ELECTRONIC CALIBRATIONS	8861	8809	8858	8863	8979
PHYSICAL/MECHANICAL CALIBRATIONS	11919	9007	11511	13460	15888
PRIORITY REQUESTS	747	398	397	1234	889
IN-SITU	674	946	960	851	1149
HOURS/CALIBRATION (AVG.)	1.69	2.15	1.95	1.82	1.6
TOTAL CALIBRATION HOURS	35,185.5	38,583.0	39672.3	40610.5	39818.0
MEAN TURNAROUND TIME	5.8	5.7	5.0	5.0	5.0
REPAIR ACTIONS	1570	1456	1430	1357	1255
HOURS/REPAIR	3.28	3.72	3.54	3.47	4.01
TOTAL REPAIR HOURS	5148.0	5415.5	5069.0	4709.1	5029.7

FIGURE 3

# MSCL PRODUCTION DATA - FISCAL YEAR 1992

## PRODUCTION-VS-HOURS PER ITEM-VS-TAT



FISCAL YEAR 1992

MSCL PRODUCTION DATA

MONTHLY PRODUCTION

ITEMS RECEIVED

AVE. HOURS PER ITEM

AVERAGE TAT

GOAL: IMPROVE TIMELINESS

FIGURE 4

# MSCL 'ITEMS' CALIBRATED

FY 85 TO 92

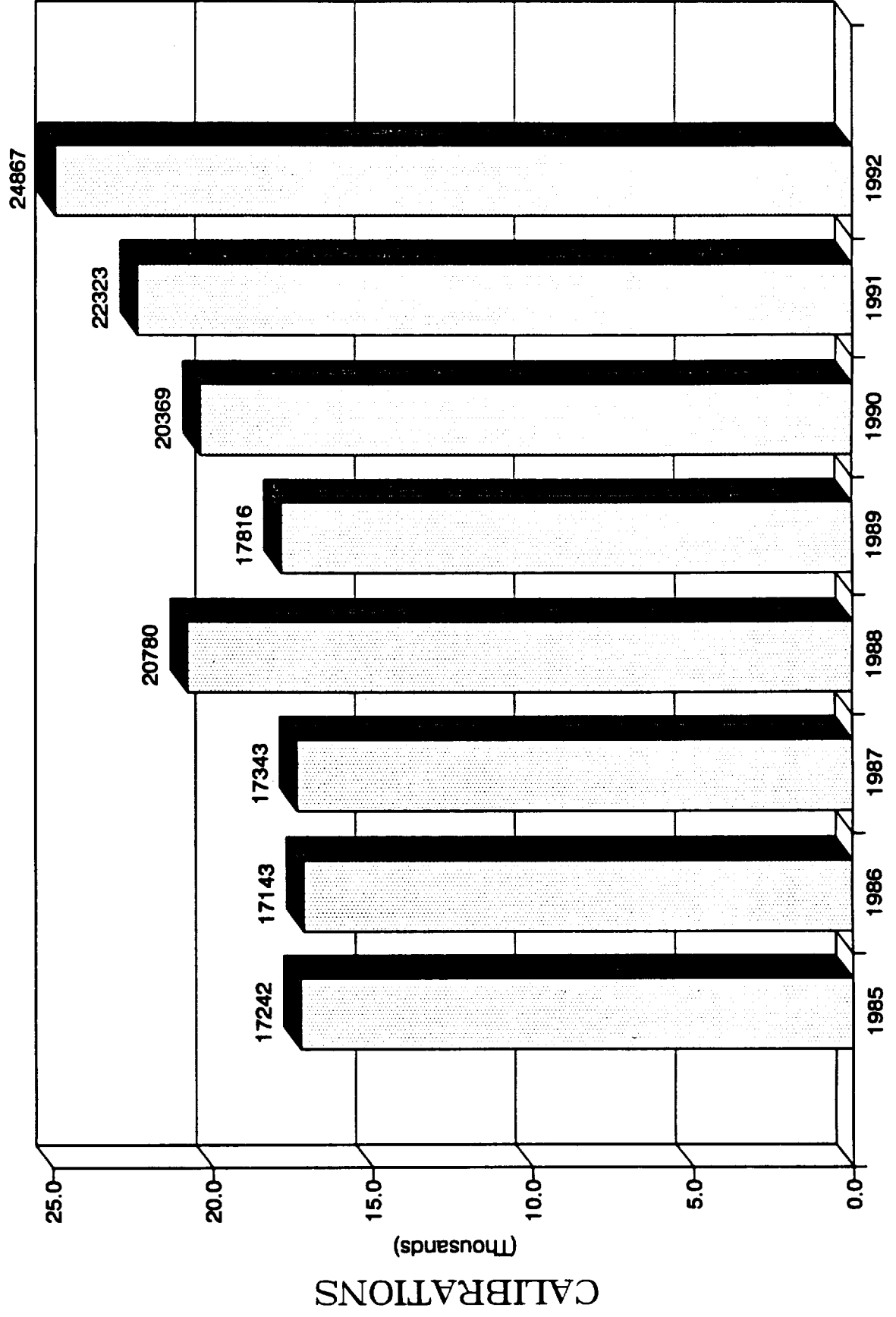
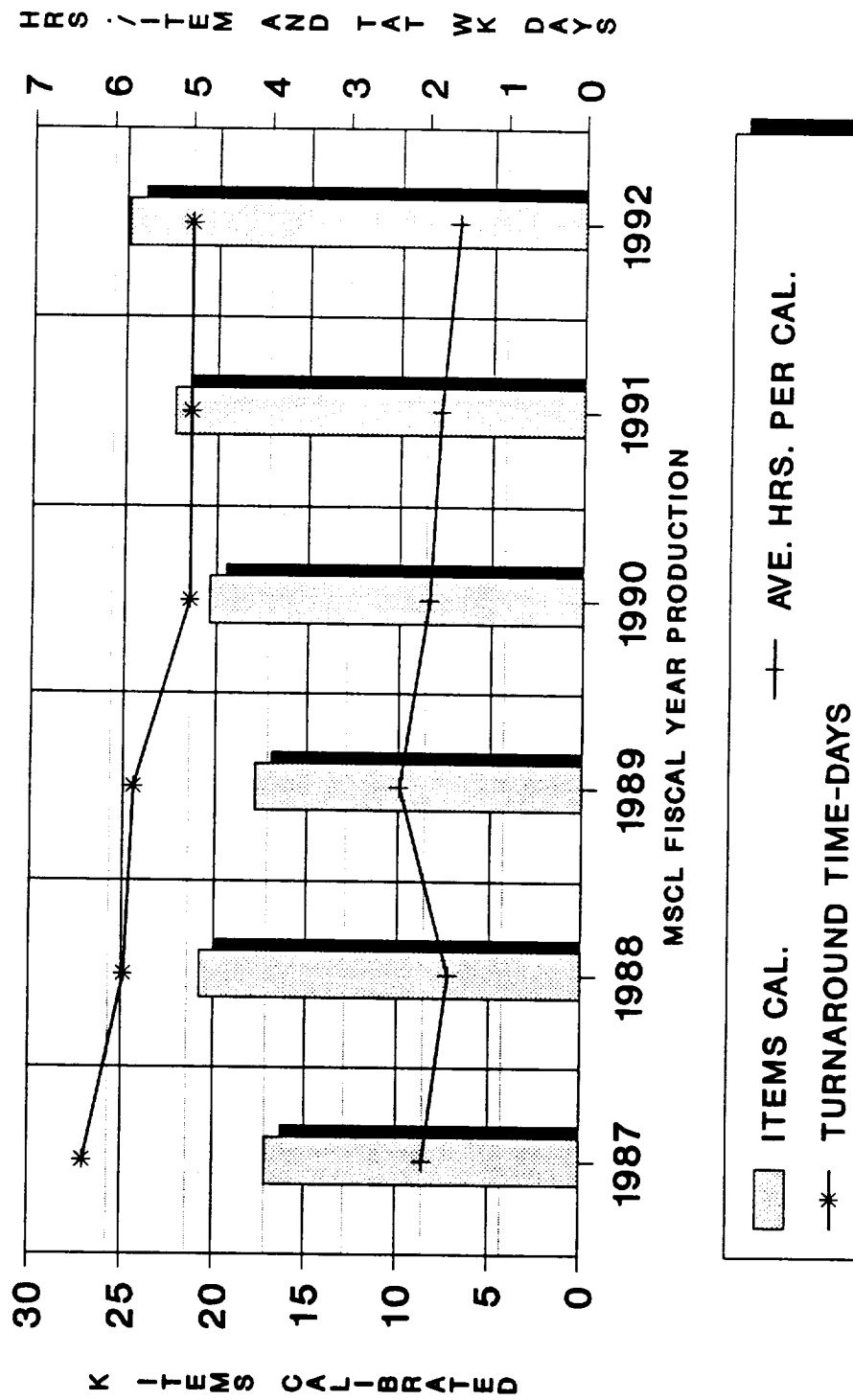


FIGURE 5

# MSCL PRODUCTION ANALYSIS

## PRODUCTION-VS-HRS/ITEM-AND-TAT



GOAL: IMPROVED TIMELINESS

FIGURE 6



# MSCL REPAIR ACTION

FY 84 TO 92

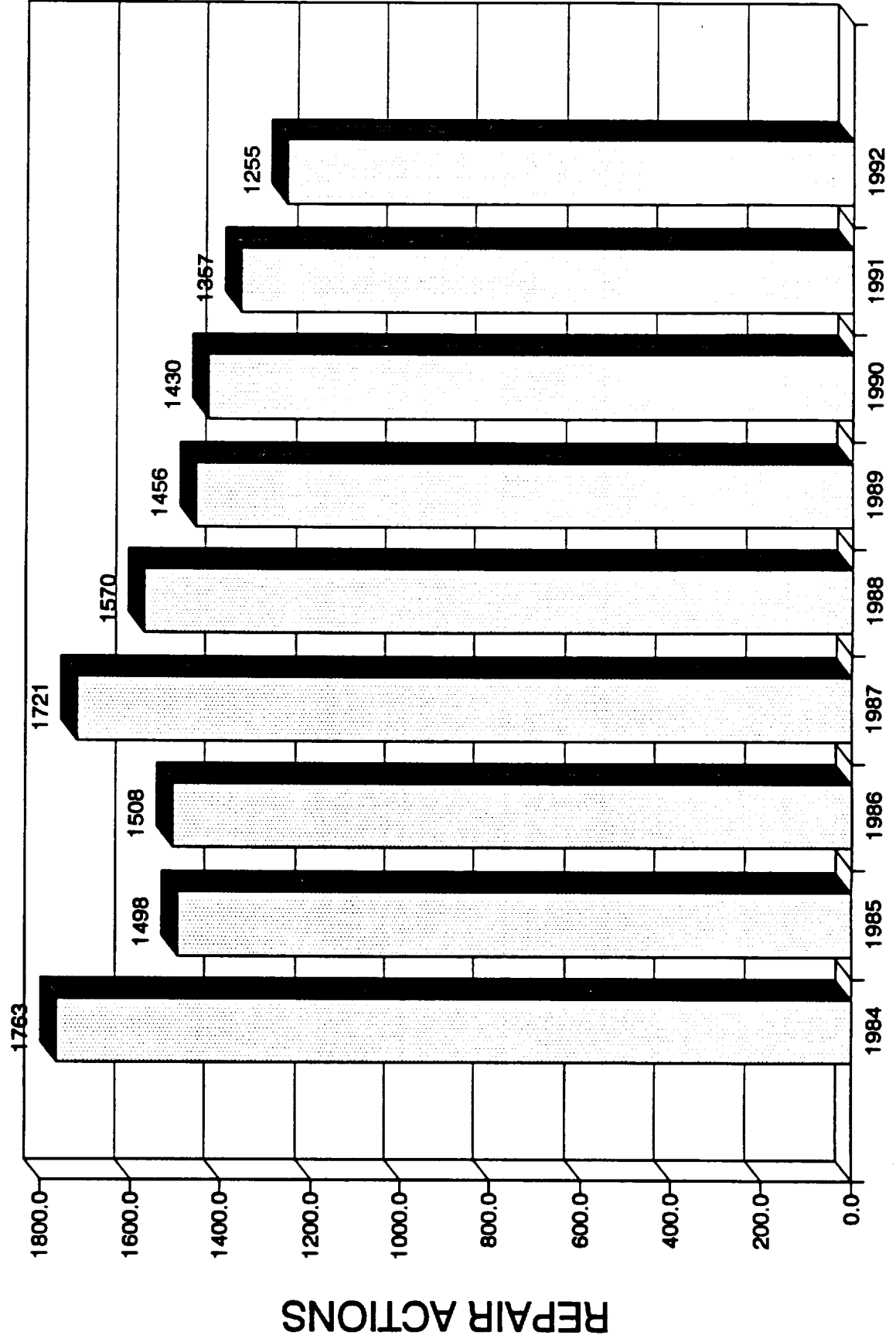


FIGURE 7

# AUTOMATIC CALIBRATION SYSTEM PRODUCTION

FY 81 TO 92

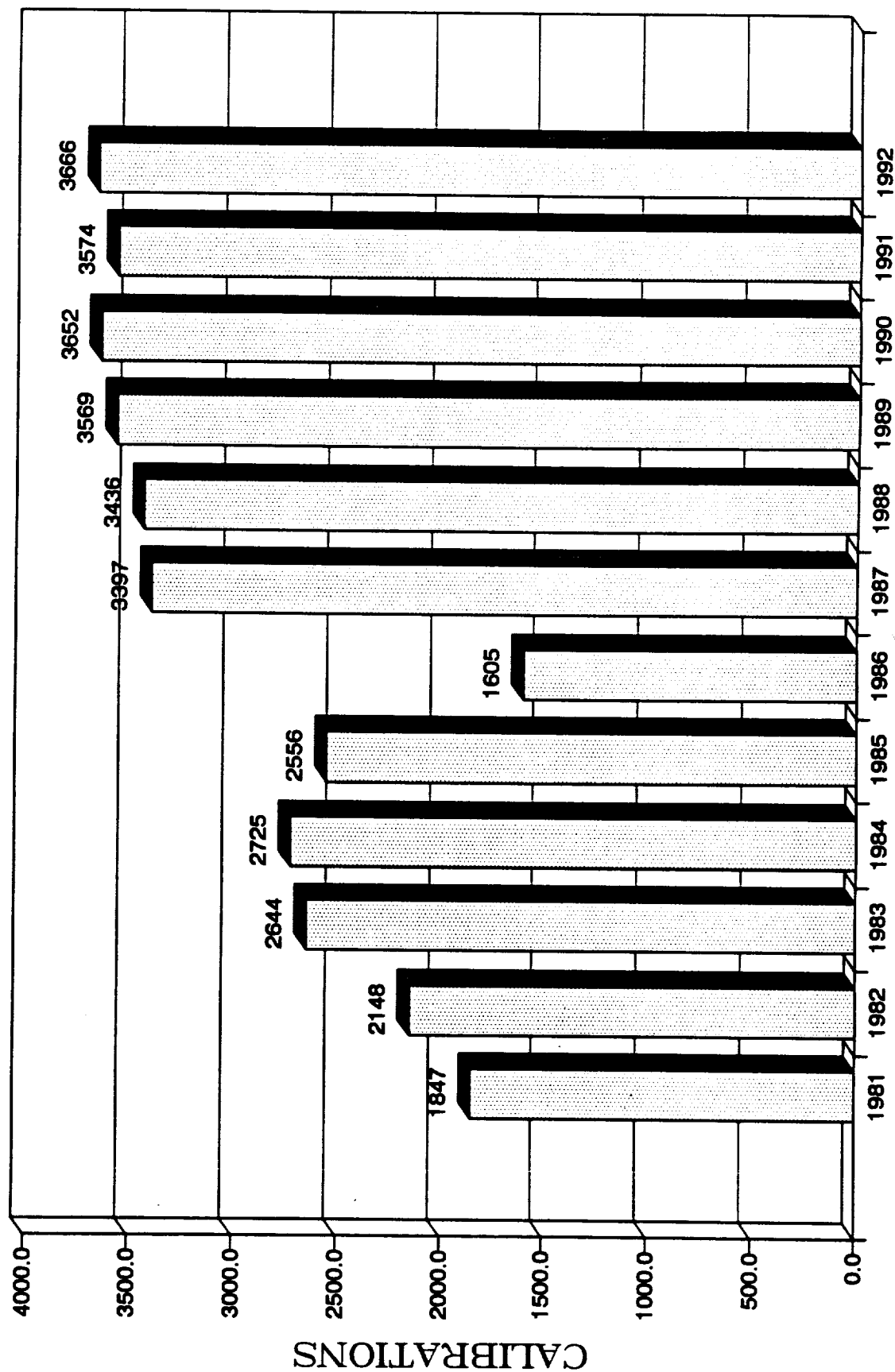


FIGURE 8

# TURNAROUND AVERAGES

FY 85 TO 92

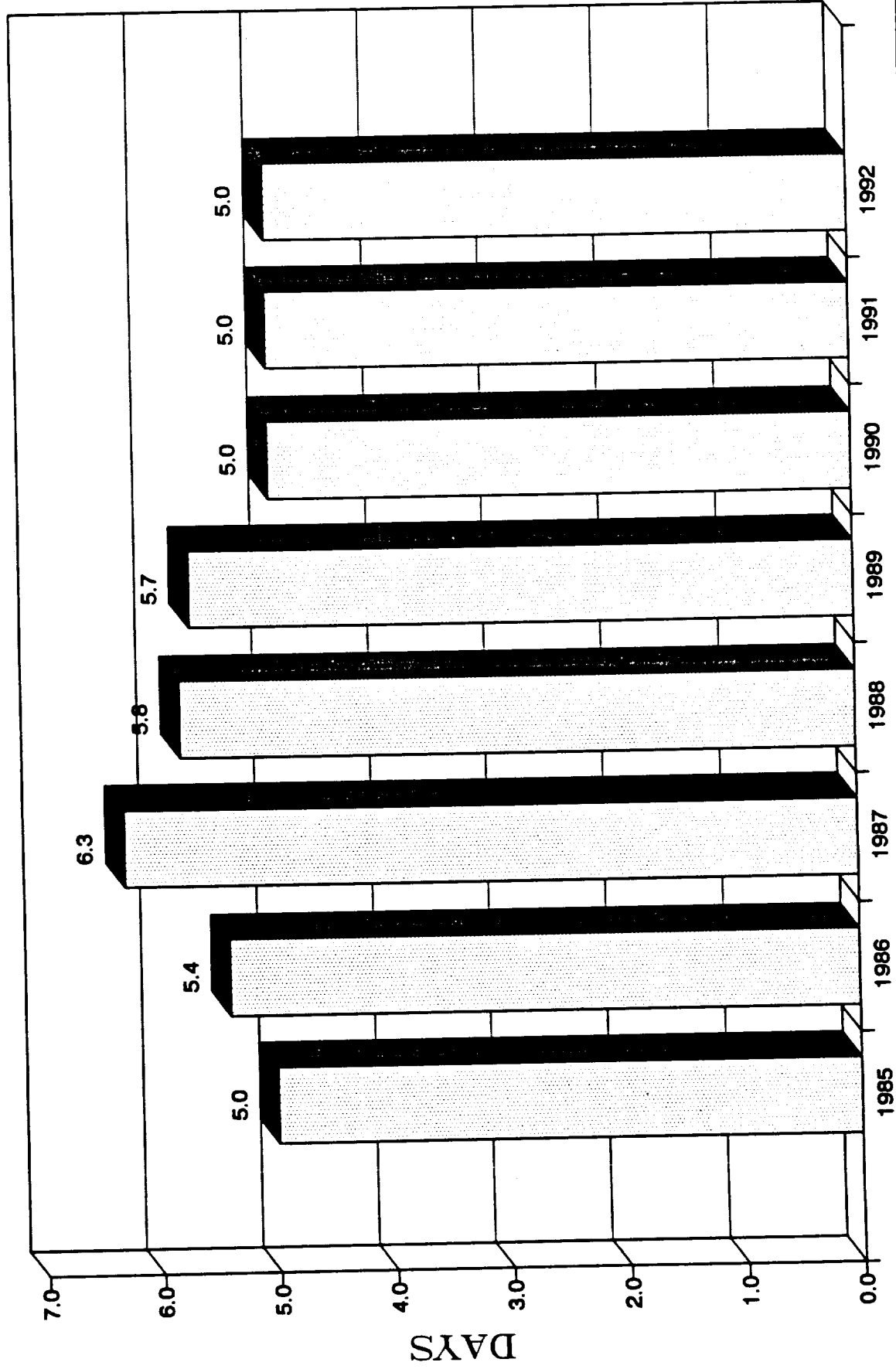


FIGURE 9

# CONDITION OF EQUIPMENT RETURNED FOR CALIBRATION

FY 92

## CONDITION AS RECEIVED

A.	WITHIN TOLERANCE	56.6 %
B.	OUT OF TOLERANCE(RPR)	1.5 %
C.	OUT OF TOLERANCE(ADJ)	6.0 %
D.	REJECTED	2.4 %
E.	LIMITED USE	32.2 %
F.	OTHER	1.2 %

## RESPONSIVENESS TO RECALL

A.	ON TIME	58.1
B.	LATE	21.8
C.	EARLY	3.0
D.	INITIAL	17.1

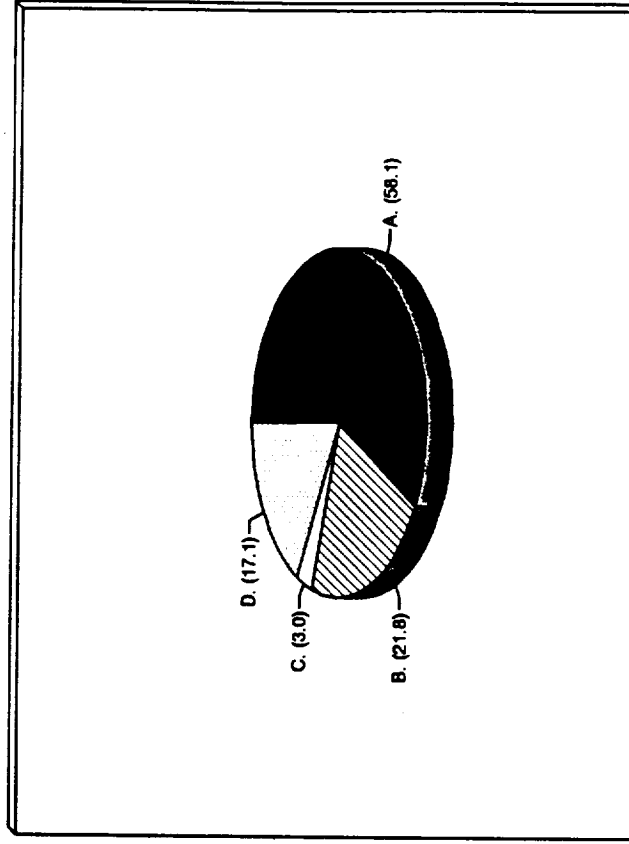
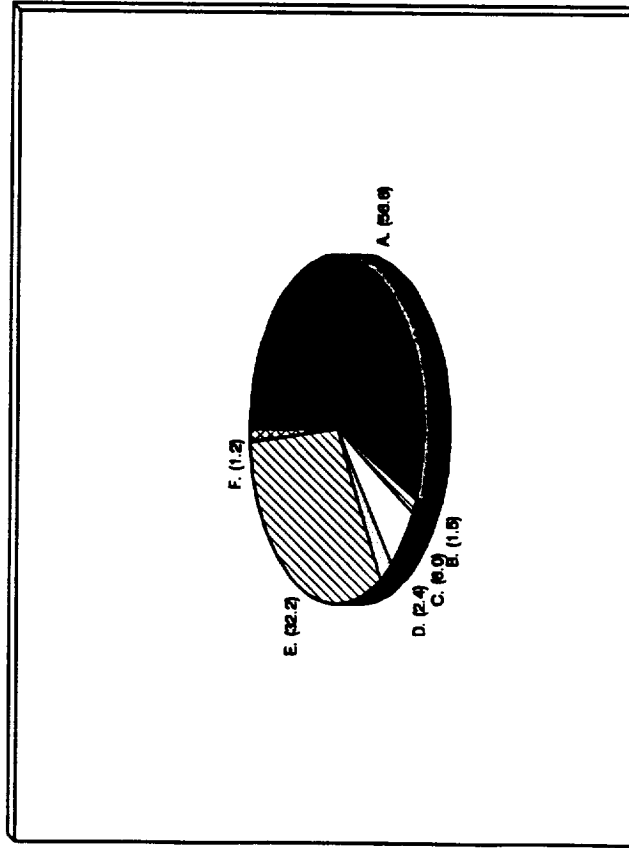


FIGURE 10

# **SUMMARY OF JSC MSCL EQUIPMENT RECALL INVENTORY FY '92**

## **TOTAL INVENTORY: PERIOD ENDING 09/30/92**

ACTIVE	16,186
INACTIVE	<u>15,102</u>
TOTAL	31,288

## **INVENTORY ACTIVITY: 10/01/91 THROUGH 09/30/92**

NET ADDITION TO ACTIVE	923
DELETED: PLACED ON INACTIVE DUE TO NO RESPONSE TO RECALL OR AT REQUEST OF USER	1,832

**JSC/MSCL REFERENCE STANDARDS ENHANCEMENT - FY92**

**INSTRUMENTS AND SYSTEMS**

	<b><u>COST</u></b>
o HEWLETT PACKARD, MODEL 5529A, LASER INTERFEROMETER MEASUREMENT SYSTEM	\$48,370
o GUILDLINE, MODEL 9930 DIRECT CURRENT COMPARATOR POTENTIOMETER	\$38,500
o HEWLETT PACKARD, MODEL 9133L 40 MEGABYTE HARD DRIVE	\$3,000
o DATA PROOF, MODEK 320A, RELAY DRIVE CIRCUIT UPGRADE	\$310
o DATA PROOF, (VRMP) UPGRADE	\$350

# **JSC/MSCL GENERAL LABORATORY CAPABILITY** **UPGRADE AND ENHANCEMENT - FY '92**

## **MEASUREMENT CAPABILITY:** **FUNCTIONAL AREA**

## **INSTRUMENT AND/OR SYSTEM**

**DIMENSIONAL**

MITUTOYO, 40 INCH DIGITAL  
HEIGHT GAGE

**LIGHT**

BLACK-RAY U. V. LAMP

**FORCE**

STRAIN SENSE, 60K LBF  
LOAD CELL

**TEMPERATURE**

ROSEMOUNT, STANDARD PRT'S  
(2 EACH)

**GENERAL PURPOSE (PMCL)**

FISHER SCIENTIFIC, (1) 10KG  
(2) 20KG STANDARD WEIGHTS

**MOISTURE**

GENERAL EASTERN, DEW POINT  
RELATIVE

**GAS FLOW**

CME, 4 LAMINAIRE FLOW ELEMENTS

**FORCE**

UNITED SYSTEM UPGRADE TO IBM 286

**MOISTURE**

NESLAB, REFRIGERATED BATH  
CIRCULATOR

# JSC/MSCL GENERAL LABORATORY CAPABILITY

## UPGRADE AND ENHANCEMENT - FY '92

(CONTINUED)

### MEASUREMENT CAPABILITY:

#### FUNCTIONAL AREA

#### INSTRUMENT AND/OR SYSTEM

GENERAL PURPOSE (EECL)

HEWLETT-PACKARD, MODEL 16380A,  
STANDARD AIR CAPACITOR SET

VIDEO

TEKTRONIX, MODEL 1410R OPT 04,  
NTSC SYNC GENERATOR WITH TEST  
SIGNAL GENERATORS

TEKTRONIX, MODEL 1780R, NTSC  
MEASUREMENT SET (2)

TEKTRONIX, MODEL 067-0916-00,  
CALIBRATION FIXTURE

GENERAL PURPOSE

KEITHLY, MODEL 263, CALIBRATOR/  
SOURCE

AUTOMATIC TEST SYSTEM

FLUKE, MODEL 74XXX-QA16SK,  
SYSTEM CONTROLLER (3)



**JSC/MSCL CALIBRATION PROCEDURE WRITING EFFORT - FY '92**

	<b><u>FY '92</u></b>	<b><u>TOTAL</u></b>
JSC MANUAL PROCEDURES (ACTIVE AND IN-ACTIVE)	55	2,331
INCORPORATED (GIDEP, AFTO, ETC.)	41	1,103
INTERIM	25	405
REVISIONS	139	324
JSC PROCEDURES SENT TO GIDEP	10	2,055

## AUTOMATIC CALIBRATION SYSTEM PROCEDURES

<u>SYSTEM</u>	<u>FY '92</u>	<u>TOTAL</u>
AUTOMATED METERS	29	256
AUTOMATED SCOPES	5	90

**PLANNED JSC/MSCL REFERENCE STANDARDS CERTIFIED DURING FY '92**

<b><u>NOMENCLATURE</u></b>	<b><u>SOURCE</u></b>	<b><u>COST</u></b>
<b>MOREHOUSE PROVING RINGS</b>	<b>NIST</b>	
<b>RANGE TO: 1,000</b>		<b>\$1,850</b>
<b>10,000</b>		<b>\$1,850</b>
<b>25,000</b>		<b>\$1,850</b>
<b>60,000</b>		<b>\$2,510</b>
<b>100,000</b>		<b>\$2,510</b>
<b>PRD ATTENUATOR</b>	<b>NIST</b>	<b>\$1,225</b>
<b>TYPE 1004</b>		
<b>HEWLETT PACKARD</b>	<b>NIST</b>	<b>\$830</b>
<b>MODEL 478-H75 THERM MOUNT</b>		
<b>EG&amp;G MODEL 300</b>	<b>NIST</b>	
<b>HUMIDITY ANALYZER</b>		<b>\$7,500</b>
<b>WEINSCHTEL, MODEL 2, ATTENUATORS</b>	<b>NIST</b>	<b>\$2,690</b>
<b>(6 EACH)</b>		

FIGURE 17

**PLANNED JSC/MSCL REFERENCE STANDARDS CERTIFIED DURING FY '92**

**(CONTINUED)**

<b><u>NOMENCLATURE</u></b>	<b><u>SOURCE</u></b>	<b><u>COST</u></b>
<b>WEINSCHTEL, MODEL M1110 THERMISTOR MOUNT</b>	<b>NIST</b>	<b>\$5,900.00</b>
<b>BLH LOAD CELL 600,000 LBF</b>	<b>MARSHALL</b>	<b>NO COST TO JSC</b>
<b>10 VOLT MAP</b>	<b>AMES</b>	<b>NASA MAP</b>
<b>AMAP</b>	<b>JPL</b>	<b>NASA MAP</b>

**PLANNED JSC/MSCL REFERENCE STANDARD CERTIFICATION DURING FY'93**

<b><u>NOMENCLATURE</u></b>	<b><u>SOURCE</u></b>	<b><u>COST</u></b>
NATIONAL INSTRUMENT, MODEL 10 FLOW METERS	NIST	AT COST
BALLENTINE, MODEL 440, MICROPOTS (4 EACH)	NIST	AT COST
THERMAL CONVERTERS FLUKE, MODEL A55 BALENTINE, MODEL 1396	NIST	AT COST
TRANSFER STANDARD FLUKE MODEL 792A	FLUKE	\$3,000
RATIO TRANSFORMERS (2 EACH) MODEL 1009 MODEL RT-23	NIST	\$3,190 \$3,190
MAP VOLTAGE TRANSFER	NIST	\$5,000
CAPACITORS (6 EACH)	NIST	AT COST

FIGURE 19

# JSC/MSCL QUALITY ASSURANCE PROGRAM ACTIVITY FY '92

<u>TYPE OF INSPECTIONS</u>	<u>FIRST QUARTER</u>	<u>SECOND QUARTER</u>	<u>THIRD QUARTER</u>	<u>FOURTH QUARTER</u>	<u>TOTALS</u>
INSTRUMENT	66	80	36	45	227
STORAGE AREAS (IN & OUT)	314	238	109	29	690
DOCUMENTATION	3,911	4,199	5,155	5,248	18,513
IN-PLACE	4	10	15	10	39
TOTAL INSPECTIONS	4,295	4,527	5,315	5,332	19,469
EQUIVALENT INSP.	1,042	1,073	1,147	1,123	4,385
TOTAL PRODUCTION	5,763	5,879	7,050	6,175	24,867
RATIO EQUIV. INSP./PROD.	18.1%	18.3%	16.3%	18.2%	17.6%
<u>TYPE OF FAILURES</u>					
DOCUMENTATION	35	45	28	15	123
TECHNICAL	2	1	3	0	6
EQUIV. FAILURES	9	10	8.6	3	129
RATIO EQUIV. FAIL./PROD.	0.2%	0.2%	0.12%	0.05%	0.1%

FIGURE 20

**National Aeronautics and Space Administration**

**John F. Kennedy Space Center**

**Center Support Operations**

**1992 CALIBRATION PROGRAM STATUS REPORT**

**Presented by**

**John P. Riley**

**Standards and Calibration**

**Engineering, Energy, and Laboratory Management Branch**

**Project Engineering and Integration Division**

**Sixteenth NASA Metrology and Calibration Workshop**

**April 20 - 22, 1993**

**Rockville, Maryland**

## INTRODUCTION

This report addresses the activities of calibration service organizations at the Kennedy Space Center (KSC) during fiscal year 1992. Material was provided by the three major NASA contractors at KSC and the report was prepared by the Engineering, Energy, and Laboratory Management Branch, Project Integration Division of the Center Support Operations Directorate for presentation at the NASA Metrology and Calibration Working Group's annual workshop.

The KSC Standards and Calibration Laboratory is operated for NASA by the Base Operations Contractor (EG&G). This facility provides measurement traceability to the National Institute of Standards and Technology (NIST) through the calibration of transfer and working standards for all organizations at KSC, and calibration program services for government and contractor organizations authorized to use base support services. The Payloads Ground Operations Contractor (McDonnell Douglas) and the Shuttle Processing Contractor team (Lockheed, Grumman and Bionetics) are tasked with providing in-situ and laboratory calibration support to their respective organizations. The acronyms BOC, PGOC, and SPC are used to identify these contractors.

## CALIBRATION RECALL CONTROL

Most calibration recall is accomplished using Metrology Information System Local Area Networks (MIS-LAN's) which link work stations to central file servers. Novell and Clipper are the standard configuration for both the BOC and SPC local area networks. PGOC utilizes their mainframe based Repeatable Maintenance Recall System for calibration recall control.



## WORKLOAD AND PRODUCTIVITY

At year end there were 64856 instruments in active recall control systems. Calibration organizations performed 85919 service events while processing 68528 instruments. This is an increase of 9% over FY 91. Service events for the last five years are categorized in Figure 1.

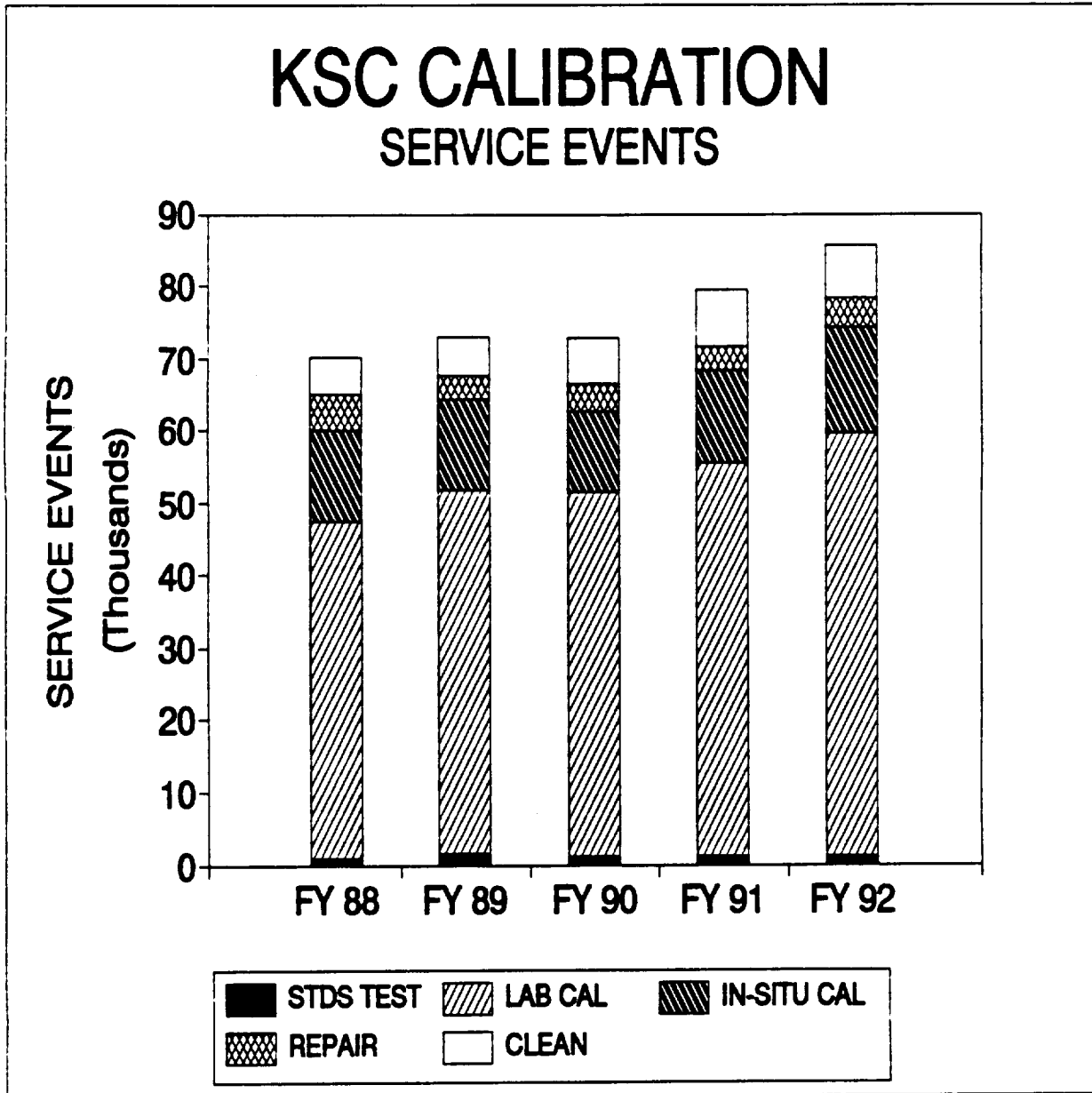


Figure 1. Calibration Service Events.

## MANNING

Total contractor calibration head count was 144 at year end. Civil Service head count is four. Contractor headcount increased by one over the FY91 level. Manning and skill mix for the last five years are given in Figure 2.

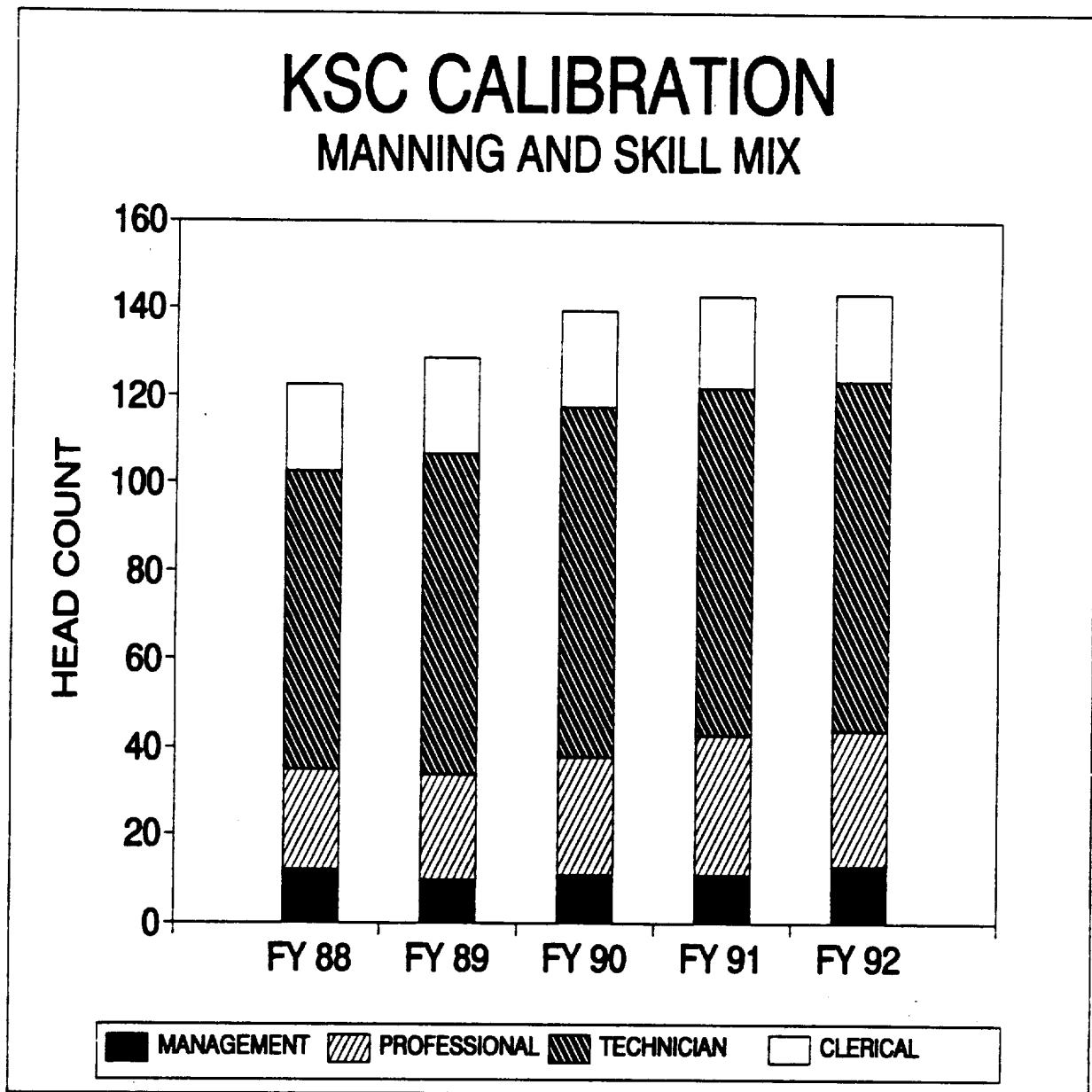


Figure 2. Calibration Manning and Skill Mix.

## NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY SERVICES

The open end contract with NIST for test services, measurement assurance program services, and standard reference materials was funded with \$56,000 in FY92. The contract will be funded with \$61,000 in FY93 bringing the total contract value to \$525,000.

### Anticipated 1993 NIST Services

Frequency Service Upgrade	Capacitance Diaphragm Gages
Solid State Volt Standards	Platinum Resistance Thermometers
Gage Blocks (Inch and Metric)	Proving Rings
Master Thread Wires	Spectral Irradiance Standards
Fiber Optic Power Meter MAP Service	Deadweight Piston Gages

### SIGNIFICANT ACCOMPLISHMENTS

Significant accomplishments in productivity improvement through automation of calibration and calibration support processes and upgrading measurement capability to support identified requirements are listed and attributed in the following paragraphs:

1. Continued program to implement ITS-90 by acquiring additional freezing points (Gallium, Indium, Tin, Zinc) and furnaces. Acquired a state of the art automated DC resistance ratio bridge and scanner switch for PRT calibration. Acquired a water triple point maintenance bath and additional triple point cells (NASA, BOC).
2. Began upgrade and automation of mass measurement capabilities. Replaced a labor intensive mechanical balance with electronic mass comparators for calibration of piston gage weights and scale test weights (BOC).
3. Established new capability to calibrate Hydra-Sets (SPC)
4. Brought vacuum calibration system, on line (SPC).
5. Developed and implemented a revised Calibration Laboratory Hazardous Waste Management Plan (SPC).
6. Developed software to automate torque wrench calibration process (PGOC).
7. Automated data reduction and data sheet printing for industrial platinum resistance temperature probes (SPC).

8. Automated RF and Microwave signal generator and attenuation calibration (SPC).
9. Acquired automated/semiautomated systems for calibration of digital multimeters, oscilloscopes, and dimensional gages (PGOC).
10. Improved in-situ calibration capability to further reduce downtime for payloads processing and Shuttle logistics depot test and measurement systems (PGOC, BOC).
11. Continued improvements to MIS-LAN's to increase ad-hoc capabilities, interfaces with metrology engineering LAN's, interfaces with KSC broad band for SPDMS 2, accessibility at remote sites, and addition of bar code reader capability (BOC, SPC).
12. Completed installation and operational testing of Vacuum Leak Rate Calibration System. Completed uncertainty analysis and developed test report formats. The system was put into production in January 1993, and leak artifact calibration services are now available to all NASA field installations (BOC).
13. Continued to support the NASA Metrology Working Group by working KSC lead items to upgrade NASA metrology infrastructure. Revised NASA Standards and Calibration Directory (NASA, BOC).

#### FUTURE ACTIVITIES

1. Continue upgrade of mass measurement capabilities by acquisition of automated mass comparator weight handler systems to replace mechanical balances (NASA, BOC).
2. Develop capability to calibrate RF power meters to support MSBLS test equipment used at TAL sites (SPC).
3. Develop systems to extend cryogenic temperature calibration for RTD's and temperature switches below the nitrogen boiling point (BOC, SPC).
4. Procure and bring on line torque calibrators to replace Apollo era opto-mechanical units (SPC).
5. Develop capability to calibrate wide band voltmeters over the frequency /voltage ranges 1 to 15 MHz and 3 to 10 volts (SPC).
6. Continue efforts to develop alternatives to CFC based cleaning and analysis technology. Provide funding to WSTF for study of gage cleaning process alternatives (NASA).

7. Identify, and establish capability to meet, the calibration requirements of Space Station Freedom MTE (NASA, PGO, BOC).
8. Revise and publish NASA Measurement Capabilities Document in 1994 (NASA, BOC).
9. Continue participation in established NASA Resistance, Volt, Temperature, Acceleration, and Microwave MAP's (BOC).
10. Continue MAP Handbook development. Obligate and cost funds allocated for the project in FY94 (NASA).

#### CONCERNS

Laboratory Facilities. The BOC, PGO, and SPC are impacted by lack of adequate calibration facility space. New measurement capabilities continue to be installed resulting in overcrowding of laboratory work areas. The SPC Calibration Laboratories which occupy VAB floor space require relocation. The SPC anticipates some consolidation by acquiring additional floor space in the Central Instrumentation Facility. However, the age of this facility, the inadequacy of the environmental control system, the delay and high cost impact of asbestos abatement required before performing even minor repairs and modifications is a concern. The Construction of Facilities Plan has a 1998 line item for a Standards and Calibration Laboratory Facility. Meanwhile, acquisition of several major measurement capability upgrades will be slipped awaiting construction of laboratory facilities.

CFC Based Cleaning/Analysis Technology. KSC has an active Ozone Depleting Substance Replacement Program and has achieved success in developing and implementing alternatives to cleaning processes which rely on Freon 113. A study of alternative methods of cleaning and analysis which would be effective for pressure gages and transducers is under way. However, an acceptable methodology which is both cost effective and environmentally benign has yet to be developed and successfully tested.



# **CENTER STATUS REPORT**

**NASA Lewis Research Center  
Cleveland, OH 44135**

**Robert S. Mattingly  
Supply and Equipment Branch  
Logistics Management Division**

**16th Annual NASA Metrology & Calibration  
Workshop**

**Rockville, Maryland  
April 20 - 22, 1993**

*(FIGURE 1)*

## **I. ABSTRACT/SUMMARY**

This report will describe the metrology and calibration activities at Lewis Research Center which is operated by Cortez III Service Corporation of Albuquerque, New Mexico. Cortez III is currently in the second year of their second - five year contract awarded by LeRC to operate the Calibration Facility.

Topics will include; Contractor responsibility and actions, Mandatory Recall system, Equipment forecasting, New equipment tracking system (Metrack), Intercenter pressure support and plans for the future.

## **II. PROGRAM OVERVIEW (FIGURE 2)**

Instrument Support Services, of Cortez III Service Corporation is responsible for three basic functions being:

- a) Acceptance testing all (100%) new and O.E.M. repaired instruments and repair and/or calibrate in all measurement disciplines.
- b) Maintain Lewis' reference and working standards in these disciplines including maintenance of a mandatory recall program.
- c) Provide engineering support through procedure generation, instrument evaluation prior to buy and special measurements.

Briefly described, the organizational structure (FIGURE 3) includes six work centers responsible for certain tasks as follows:

**SUPPORT SERVICES** (Logistics) is responsible for the logistics and property management functions such as data processing, work order call-in and record keeping of mandatory recall information.



**FLOW CALIBRATION** is located at LeRC and performs gas and liquid flow calibrations, maintenance and calibration of all Lewis' gas analysis systems, mass spectrometer type leak detection equipment and vacuum pumping systems.

**QA/ENGINEERING** enforces the Quality Assurance Plan and supports any special measurements or test evaluation requirements.

**GENERAL INSTRUMENT SERVICES** maintains all video, communications and analog instrumentation.

**PHYSICAL/MECHANICAL CALIBRATION** is responsible for calibration of force, temperature, torque, pressure and the primary pressure standards lab.

**ELECTRICAL/ELECTRONIC CALIBRATION** maintains all the digital and controllable electronics as well as the primary electrical standards lab.

**CALIBRATION & REPAIR ACTIVITIES FY'92**

◆ Acceptance Inspections	3,220
◆ Flow Calibrations	585
◆ General Instrument Services	3,660
◆ Physical/Mechanical Calibration Services	4,099
◆ Electrical/Electronic Calibration Services	3,074

### III. MANDATORY RECALL

Trying to implement a mandatory recall program at LeRC in FY'87 was very frustrating. Meeting then with members of the Equipment Utilization Committee and the Instrument Applications Office indicated complete agreement with a recall program, but from 278 questionnaires sent throughout Lewis, only 52 responses from users were returned identifying 521 instruments to be included in the database. Currently, we have 2,173 user items and adding 1,260 items on recall from the Calibration Laboratory's GFE equipment. Along with the great success of the mandatory recall, other spin-offs have resulted. The Cal Lab's compliment has decreased and the overall work production has increased in all disciplines.

Research in Space Station Power, Aeronautics and the Hypersonic Aircraft have resulted in increased instrument buys which have impacted scheduling at the Calibration Lab. The biggest problem area has been in the General Instrument Services area (amplifiers, signal conditioners, power supplies and chart recorders) where we are trying to automate even more and where additional manpower and standards are needed.

### IV. EQUIPMENT FORECASTING (FIGURE 4)

In the past, Instrument Pool and user forecasting was performed in a lengthy laborious spreadsheet system where research divisions had to provide instrument needs for research programs in the upcoming year. In fiscal year '93, a new abbreviated method of instrument forecasting was implemented through a center wide networking computer system. With the early success of this system, fiscal year '94 instrument forecasting is being completely filled

via the Lewis Instrument Pool System (LIPS). Each R & D user (with funds) may submit a request of needed instruments through LIPS which is then compiled for purchase which in turn permits large quantity discount buys.

## **V. EQUIPMENT TRACKING SYSTEM (METRACK)**

In September of 1991, when support for NASA Metrology Information System (NMIS) was discontinued, it was decided that NMIS would be used to store only history data on instruments. The first step in breaking away from NMIS was redesign of the Calibration Lab work order to take the place of the previously used 1621 document. The new work order was custom designed to fit the needs of the Calibration Lab. Next, a mandatory recall database system was created based on input and suggestions from various sources. This provided immediate control over the mandatory recall situation, since NMIS proved to be unreliable. The next step involved tying the mandatory recall system into the work order system. This new metrology tracking system (Metrack) provides immediate update of mandatory recall records each time a recall item is serviced. In addition to the many reports that can be generated, it provides history data sheets to aid the technician in servicing of equipment.

## **VI. INTERCENTER SUPPORT**

The Calibration Laboratory has a unique capability of testing up to 20 pressure transducers at one time over temperature conditions from -20°F to 225°F. This enabled the Space Shuttle Program to calibrate pressure transducers (150 Gould, 280 Kulite sub-miniature) over flight temperature range and replace 30 Gould and 40 Kulite pressure transducers on the

Columbia that did not meet Space Shuttle Program specifications. These transducers were evaluated to determine the aerodynamic load distribution on the Orbiter Columbia.

## **VII. NEW INITIATIVES**

Currently Cortez III is managing a contract with Sundstrand Data Corporation in Washington who are calibrating three axis micro-gravity accelerometers and their electronics for a Lewis Space Acceleration Measurement System (SAMS) program. Cortez III with the consent and financial approval from Lewis, will develop an in-house capability which will relieve present shipping and communications problems which would be more cost effective.

---

## Calibration Laboratory

**Cortez III is responsible for Instrument Support Service  
in the following areas:**

- ◆ Maintenance and Calibration
- ◆ Acceptance Testing (100%) of New and O.E.M. Repaired Instruments
- ◆ Priority and Onsite Service
- ◆ Maintain a Mandatory Recall System
- ◆ Instrument Pick-up and Delivery Service
- ◆ Telephonic Work Order System

---

**Cortez III Service Corporation**



---

## Calibration Laboratory Staffing

◆ Section Manager	1
◆ Supervision	4
◆ QA/Calibration Engineer	1
◆ Flow Calibration Engineer	1
◆ Technicians	23
◆ Systems Analyst	1
◆ Logistics Support	3
◆ Computer Operator	1
◆ Secretary	1
◆ Supply Technician	1

<b><i>TOTAL COMPLIMENT</i></b>	<b>37</b>
--------------------------------	-----------

---

**Cortez III Service Corporation**

*(FIGURE 3)*

---

# **NASA Lewis Research Center Lewis Instrument Pool System - (LIPS)**

**WELCOME TO THE LEWIS INSTRUMENT POOL SYSTEM (LIPS)**

**The Processing for the Prior Year (FY'92)  
closed on December 31, 1991. Requests entered  
before that date cannot be modified or deleted.**

**Requests entered after January 1, 1992 will be included  
in the processing cycle for Current Year (FY'93)**

**If you are a "New Forecaster", please remember to enter  
your personnel information.**

**Have a great day!**

**Press <enter> to continue**

*(FIGURE 4)*





**National Aeronautics and Space Administration  
John C. Stennis Space Center  
Measurement Standards and Calibration Laboratory**

## **METROLOGY PROGRAM STATUS REPORT — 1992**

**April 20, 1993**

**Presented by**

**Herman L. Watts  
Technical Manager  
Technical Operations Division**

**Prepared by**

**Thomas E. Weiss  
Sverdrup Technology, Inc.  
SSC Group**

**Sixteenth NASA Metrology and Calibration Workshop**

**Rockville, Maryland**

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# **METROLOGY PROGRAM STATUS REPORT – 1992**

## **1. SCOPE**

This report provides information relative to the Metrology Program at John C. Stennis Space Center (SSC), Mississippi, which conducts program operations through the SSC Measurements Standards and Calibration Laboratory (MS&CL), hereinafter referred to as the MS&CL or the laboratory. Information in this report includes MS&CL mission, staffing, upgrades, activities [including NASA Metrology Information System (NMIS) and related Stennis Metrology Management System (SMMS) activities], production, training, and future plans.

## **2. MISSION**

The primary mission of the MS&CL is to provide services for instrumentation calibration, repair, and cleaning/maintenance in support of the Space Shuttle Main Engine (SSME) testing program. The secondary mission is to provide these services for the other 18 federal and state agencies in residence at SSC. Upcoming NASA projects that will require SSC MS&CL support are the Advanced Solid Rocket Motor (ASRM), the National AeroSpace Plane (NASP), and the New Launch System (NLS).

## **3. ADMINISTRATION**

All SSC Metrology Program activities are handled by the SSC MS&CL, which is operated for NASA by Sverdrup Technology, Inc., headquartered in Tullahoma, Tennessee. Although the MS&CL operates as an organizational unit of the Sverdrup SSC Group Technical Services Department, its activities and operations are subject to the authority of the NASA/SSC Technical Operations Manager.

## **4. REQUIREMENTS**

All MS&CL technical operations are subject to the policies and procedures set forth in applicable NASA Management Instructions and in the Sverdrup Quality Assurance Manual. MS&CL operations are also subject to surveillance and inspection by the Defense Contract Management Command (DCMC). To ensure

MS&CL compliance with all operational requirements, a Standards and Calibration Laboratory Operating Procedures Manual has been written and implemented.

Quality Assurance (QA) uses statistical process control (SPC) to record, track, and provide trend analyses and statistics of defects discovered in the final process of calibration service deliverables. Defect analysis data are used by MS&CL to control/correct defects to the lab/technician level. Defect statistics, provided to the laboratory weekly, monthly, quarterly, and annually, are used to control and improve calibration processes.

## **5. STAFFING**

The SSC MS&CL consists of six primary service areas:

- Metrology Engineering
- Primary Standards/Calibration
- Physical/Mechanical Calibration
- Electronic Calibration/Repair
- Prototype Development
- Laboratory Support Services.

The MS&CL is staffed by contractor personnel as follows:

<u>Position</u>	<u>Number</u>
Manager	1
Engineers	2
Supervisors	3
Technicians	45
Administrators	6
Courier	<u>1</u>
Total	58

Staffing was increased in 1992 from 48 to 58 due to Sverdrup reorganization that added the Prototype Development Laboratory to the MS&CL section.

## 6. UPGRADES

A three-phase project to modernize and upgrade MS&CL facilities and capabilities was planned in 1985, initiated in 1986, and completed in March of 1992. Phases I and II provided a laminar flow design Primary Standards Laboratory and a facility for laboratory management and engineering metrology services. Phase III provided a major upgrade of the Electronic Calibration and Repair Laboratory by the addition of 6332 ft<sup>2</sup> to the facilities in Building 8110. This project upgraded marginal facilities, increased laboratory space from 11,842 to 22,625 ft<sup>2</sup>, and resulted in an excellent Measurement Standards and Calibration Laboratory.

During the period of this project there was also an intensive modernization and upgrade of MS&CL equipment to improve laboratory capability, process, productivity, and services. Significant improvements were attained by the replacement of obsolete standards and the upgrade of existing standards, the development of new measurement capabilities, and the procurement of equipment to automate the calibration process. Approximately 85% of laboratory calibration processes were computer automated, utilizing calibration software programs written by SSC MS&CL personnel. NASA's procurement of the laboratory standards and the expansion/upgrade of facilities and operations were achieved by funding as indicated in Figure 1.

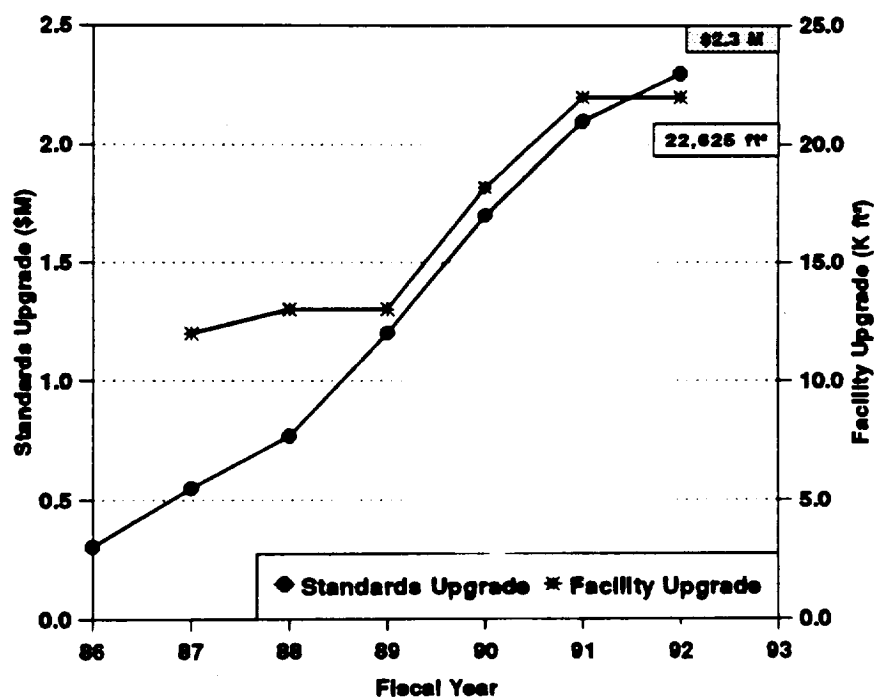


Figure 1. SSC MS&CL Upgrades.

During FY92, major improvements were made in the following MS&CL measurement areas:

- Dewpoint
- Dimensional Measurement
- AC/DC Voltage
- Temperature
- Mass
- Force
- Wind Tunnel
- Gas Flow
- Automation.

The MS&CL has also developed new capabilities in the following areas:

- Repair/calibration of the Guildline auto-salinization instruments
- Uninterruptable power supply (UPS) repair and preventive maintenance program
- Electric field mill instrumentation calibration used for sitewide lightning detection
- Software applications (Section 7.4).

Planned future procurements will provide upgrade of MS&CL measurement capabilities in the following areas:

- Vibration
- Fiber Optics
- Force
- Flow (Gas & Liquid)
- Roughness Measurement
- Laser Dimensional Measurement
- Automatic Vacuum Calibration
- Automatic Instrumentation Calibration
- Automatic Temperature Calibration.

## **7. ACTIVITIES**

### **7.1 Personnel**

SSC MS&CL personnel participated in three separate artifact measurements in the NASA Accelerometer Measurement Assurance Program (AMAP) sponsored by NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California. Measurement data taken during SSC MS&CL calibration of transfer standard accelerometers were reported and evaluated by JPL and were well within the "... comparison calibration uncertainty over the test frequency range." The MS&CL's participation in the NASA Measurement Assurance Program (MAP) will improve the uncertainty of the SSC accelerometer measurement process.

An SSC MS&CL technician initiated a technical paper that was accepted for presentation at the Annual National Measurement Science Conference (MSC) in Anaheim, California. The technical paper (entitled "Semi-Automated Mass Weight Calibrations") presented information and a process for mass calibration.

### **7.2 TMAP**

The Temperature Measurement Assurance Program (TMAP), initiated by the SSC MS&CL through the NASA Metrology and Calibration Working Group and funded by NASA HQ as a Research Technology Operations Plan (RTOP), is nearing completion of the first phase. During 1992, artifacts were sent to nine participating NASA installations for temperature measurement at the triple point of water (TPW). MS&CL engineering and technical staff have completed planning, implementation, coordination, baseline measurements, data collection, and monthly reports of TMAP activity; and plans are under way to initialize the second phase, which will include measurement comparisons using fixed-point intrinsic standards. A presentation of TMAP progress and accomplishments will be made at the next NASA Metrology and Calibration Working Group annual workshop.

This NASA-wide TMAP will serve to assess and intercompare the ability of participants to prepare, measure, and document a TPW resistance measurement of Standard Platinum Resistance Thermometers.

### **7.3 NMIS**

No major problems were encountered with the NASA Metrology Information System (NMIS); however, there were occasional periods of downtime due either to mainframe downtime or to NMIS inflexibility in retrieving meaningful data in customized report format. (Presently, NMIS provides only "canned" reports.) Although the SSC MS&CL continues its active use of NMIS as its only Calibration Management System (CMS), it is planning to replace NMIS in FY93 with a new CMS identified as the Stennis Metrology Management System (SMMS).

MS&CL personnel have identified requirements intrinsic to SMMS design and development. SMMS modules, tables, files, and transaction reports, together with descriptive information of the system operating requirements and a block-by-block description of the new SMMS Calibration Maintenance Report (CMR), were developed. The CMR is designed to provide calibration action/status/data information for the customer without the use of codes. In addition, it will be used to drive the new SMMS.

Design, development, and installation of software for the initial implementation of the new SMMS were completed by SSC Data Services personnel on October 16, 1992. This software initiated the use of the SMMS Technical Work Request (TWR) module, which enables the data input and generation of TWR's. This module will also create the database required to print the new CMR.

Development and implementation of the new SMMS is as follows:

- Phase I – Processing of non-NASA equipment (FY93)
- Phase II – Processing of online NASA equipment (FY93)
- Phase III – Implementing a paperless system (TBD).

### **7.4 Software Applications**

A UNIX-based workstation, with network interface cards and software operating system recommended by the MS&CL for NASA procurement in FY91,



has been received and is being configured for operation with the MS&CL local area network (LAN). This workstation will be used as a network server for the SMMS, with networking services provided by LAN Manager for UNIX, and as a server for Hewlett-Packard's Shared Resource Manager (SRM). The SRM function will allow for the central storage of calibration data taken by the older Hewlett-Packard equipment controllers, thereby preserving a significant investment in software applications generated by MS&CL technicians for equipment calibrations.

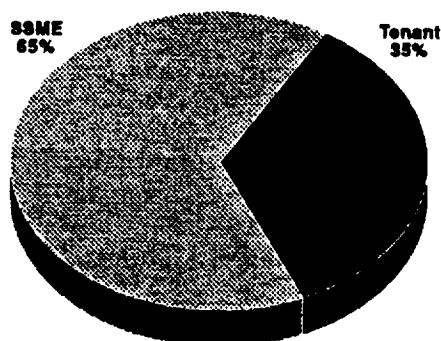
Nineteen new equipment controllers were also received by the MS&CL as part of the FY92 purchase buy. The controllers are 386SX machines equipped with network interface cards and IEEE-488 general purpose interface bus (GPIB) cards, which will facilitate their use on the LAN and as calibration equipment controllers. These machines will replace/augment existing Hewlett-Packard controllers that have been in use since 1986, and standardize the use of DOS-based machines throughout the laboratory. Formal training was also provided for two MS&CL personnel to fulfill the duties of LAN system administrators, which will help ensure proper system operation, maintenance, and administration.

## 8. PRODUCTION

Total SSC MS&CL calibration service production in 1992 is shown in Table 1. (The functions identified in this listing represent the internal structure of the laboratory.) Figure 2 provides breakdown of calibration services by user.

**Table 1. SSC MS&CL Total Production – 1992**

<u>Function</u>	<u>Units</u>
Primary Standards and Calibration	650
Routine Electronic Calibration	2,311
Electro/Mechanical Calibration	5,513
Water Level Recorder Repair	855
Instrument Repair*	1,223
Instrument Cleaning	<u>2,651</u>
Total	13,203
<u>*Includes Gas Monitors</u>	



**Figure 2. SSC MS&CL Calibration Services by User.**

This year's total production of 13,203 reflects a decrease of 2,085 units (15.8%) from last year's production of 15,288. The production decrease is due to a decrease in water-level recorder repair, and to the decrease of some onsite customer request services in most laboratory measurement discipline areas. Table 2 provides breakdown of SSC MS&CL production by measurement discipline.

**Table 2. MS&CL Production by Measurement Discipline**

Measurement Discipline	Number of Units	Hours per Unit	Percent in Tolerance
Acoustics, Vibration, and Shock	69	4.4	100
Pressure, Vacuum	1,559	2.8	97
Dimensional	1,221	3.4	96
Electrical/Electronic	2,177	2.9	94
Frequency Standards and Counters	359	2.5	99
Radiometers/Photometry	75	4.2	94
Temperature/Humidity	345	4.5	95
Ionization/Radiation	10	22.0	100
Microwave/RF	153	2.2	100
Oscilloscopes, etc.	512	2.6	97
Liquid/Gas Flow	404	6.8	98
Mass, Force, and Torque	1,590	1.4	96
Gas Monitors	471	1.1	100
Water Level Recorder	855	5.0	*
Instrument Cleaning	2,651	**	*
Instrument Repair	752	5.9	*
<b>Total</b>	<b>13,203</b>	<b>2.8</b>	<b>96</b>

\* Not applicable

\*\* Hours included in calibration times

## **9. TRAINING**

SSC MS&CL Personnel attended seminars, workshops, and video conferences throughout the year. On-the-job training and cross-utilization of personnel also added to the technical and professional knowledge and skills of MS&CL personnel. Formal training was provided in the following key areas:

- Moisture Measurement
- LAN System Administrator
- Business Writing Skills
- Quality and Productivity
- Management
- Onsite ADP Training
- 1992 Measurement Science Conference
- National Conference of Standards Laboratories (NCSL)
- NASA Workshop.

To improve managerial and technical skills, formal training is projected for FY93 in the following areas:

- Microwave Calibration
- Oscilloscope Calibration
- Optical Calibration
- Gas Flow
- GPIB Instrumentation
- Accelerometer Calibration
- Onsite ADP Training
- 1993 Measurement Science Conference
- NCSL
- NASA Workshop.

## **10. FUTURE PLANS AND ACTIVITIES**

The MS&CL's immediate plans for FY93-94 are to

- Implement a process enabling transfer of calibration status and data to onsite users

- Provide for an administrative LAN for the laboratory
- Develop and implement new SMMS, designed to fit local needs and replace NMIS at SSC.

Plans to add additional MS&CL space in FY96 will complete expansion to meet NASA's future needs in support of the planned ASRM testing and NLS programs. Additional procurement of new equipment will continue to upgrade and increase MS&CL capabilities in automated calibrations flow, pressure, temperature, vibration, and laboratory standards. The TMAP will be conducted for all NASA locations that wish to participate, with expectation of expanding the program in future years to improve temperature measurement throughout NASA.

**WALLOPS FLIGHT FACILITY  
CALIBRATION AND REPAIR PROGRAM  
STATUS REPORT**

**FY 92**

**BY**

**ROBERT L. NOCK**

**SIXTEENTH NASA METROLOGY/CALIBRATION WORKSHOP  
POTOMAC INN  
ROCKVILLE, MARYLAND  
APRIL 20-22, 1993**



**WALLOPS FLIGHT FACILITY  
CALIBRATION AND REPAIR LAB**

**STAFFING**

**CIVIL SERVICE**

<b>ELECTRONIC TECHNICIANS</b>	<b>3</b>
<b>CLERK-STENOGRAPHERS</b>	<b>1</b>

**CONTRACTOR SUPPORT (CSC)**

<b>ELECTRONIC TECHNICIANS</b>	<b>6</b>
<b>MECHANICAL TECHNICIANS</b>	<b>1</b>

<b>TOTAL STAFFING</b>	<b>11</b>
-----------------------	-----------

# CALIBRATION/REPAIR SERVICE ACTIVITY LEVEL

## FY 92

<u>NUMBER OF CALIBRATIONS</u>	
ELECTRONIC	2118
MECHANICAL	731
TOTAL	<u>2849</u>

<u>NUMBER OF REPAIR ACTIONS</u>	
ELECTRONIC	214
MECHANICAL	5
TOTAL	<u>219</u>

<u>TOTAL NUMBER OF CALIBRATION AND REPAIR ACTIONS</u>	
	3068



## **LOAN POOL ACTIVITY**

<b>NUMBER OF ITEMS IN POOL:</b>	<b>242</b>
<b>INSTRUMENTS LOANED:</b>	<b>196</b>
<b>AVERAGE LOAN PERIOD:</b>	<b>3 WEEKS</b>

### **INSTRUMENTS - HIGH DEMAND**

**OSCILLOSCOPES**

**POWER SUPPLIES**

**RECORDERS**

**MULTIMETERS**

### **INSTRUMENTS - LOW DEMAND**

**ATTENUATORS**

**FUNCTION GENERATORS**

## **PROBLEM AREAS**

- **HIGH COST OF DOING BUSINESS**
  - **RECERTIFICATION OF STANDARDS**
  - **VENDOR REPAIR AND CALIBRATION TURN AROUND**
- **EQUIPMENT REPLACEMENT**
  - **LOAN POOL ACTIVITY IS LOW BECAUSE OF OUTDATED EQUIPMENT - REPLACEMENT COSTLY**
- **AVAILABILITY OF PARTS**
  - **SOME EQUIPMENT NO LONGER SUPPORTED BY MANUFACTURER**

## **FUTURE ACTIVITIES**

- **UPGRADE LOAN POOL EQUIPMENT AND TEST INSTRUMENTATION**
- **PREPARE FOR METRIC CAPABILITIES**

## **UPDATES**

- **TRAINING**
  - **HAND SOLDERING**
  - **CRIMPING, CABLING, AND HARNESSING**
  - **REPAIR, REWORK, AND MODIFICATION**
- **ELECTRICAL STANDARDS / MECHANICAL STANDARDS**
  - **RECENTLY RECERTIFIED**



**NASA Johnson Space Center  
White Sands Test Facility**

---

# **1992 Center Report**

**Presented by  
Troy J. Estes**

**at the  
NASA Metrology and Calibration Workshop  
April 20–22, 1993**



# White Sands Test Facility 1992 Center Report

## 1.0 Introduction

This report describes the metrology and calibration activities of the NASA Johnson Space Center White Sands Test Facility (WSTF) for 1992.

## 2.0 Calibration Program Overview

The calibration program had a stable year in which new equipment was brought on line, plans were made to replace equipment, and most established automation objectives were met. Five new automated calibration stations were made operational, and a sixth station was updated. One project was canceled because the proposed temperature bath controller failed acceptance testing.

## 3.0 NMIS Activities and Problems

WSTF is not a user of NMIS, so there are no activities or problems to report.

## 4.0 Calibration Program Analysis

### 4.1 Staffing

Calibration program staffing included 1.0 civil servants and 16.5 support contractors. Contractor staffing is broken down by function in Table 1.

**Table 1. Contractor Staffing by Function**

<b>Function</b>	<b>Staffing</b>
Calibration Support (Programming, Secretarial, Supervision)	3
Electrical Calibration	6.5
Mechanical Calibration	7

## 4.2 Work Analysis

The total number of instruments calibrated was 7199. The total number of instruments repaired was 282. A breakdown of the workload by major calibration area is shown in Table 2.

**Table 2. Workload by Major Calibration Area**

Area	Instruments Calibrated	Instruments Repaired	Total Hours
Electrical	2 947	221	9 300
Mechanical	4 252	61	11 000
Total	7 199	282	20 300

Electrical calibrations increased 1.8 percent over 1991 figures, and mechanical calibrations decreased 2.4 percent. Total calibrations were down 0.7 percent over the previous year. Repair requirements increased by 10 percent.

The calibrated instrument loan pool contained 450 electrical and mechanical instruments. Approximately 80 loans were made this year.

The average time required for calibration in each of the major instrument categories is shown in Table 3. This year's figures are historical averages obtained from the metrology data base.

## 5.0 Calibration System Development

### 5.1 New Calibration Stations

An automated EG&G/Flow Technology OT400 liquid flow calibrator was installed, replacing the manually operated Cox liquid flow calibrator. The OT400 reduced flow meter calibration time from 2 hours to 45 minutes. Ease of operation and accuracy exceeded expectations.

An automated MKS VCGS-200 vacuum calibrator was procured and installed. It replaced an obsolete, manually operated vacuum calibrator. Four vacuum devices can now be installed and pumped down unattended, reducing the typical calibration time by up to 3 hours per calibration.

A 0-70 kg load cell calibrator was designed, fabricated and installed. The calibrator uses precision weights to apply a force and a mobile computer-aided-calibration cart for instrumentation.



Table 3. Average Calibration Time by Instrument Category

Instrument	Time (hours)
<b>Pressure and Vacuum</b>	
Transducers	1.0 <sup>a</sup>
Dial Gauges	1.2
Vacuum Devices	3.5
<b>Dimensional</b>	
Micro Flats	40.0
Micrometers, Calipers	2.1
Gauge Blocks	40.0
<b>Mass and Force</b>	
Load Cells	5.4
Electronic Balances	2.2
Double Pan Balances	6.0
Small Ohaus Balances	2.0
<b>Temperature and Humidity</b>	
Thermocouples	1.7 <sup>b</sup>
Recorders	4.8
Rain Gauges	1.0
<b>Electrical and Electronic</b>	
Standards	4.0
Frequency Counters	2.2
Oscilloscopes	2.6
Video Equipment	2.0
Communications Equipment	2.0
<b>Miscellaneous</b>	
Liquid and Gas Flow Devices	0.75

<sup>a</sup> 12 similar transducers simultaneously

<sup>b</sup> 20 thermocouples simultaneously

An automated Thunder Scientific 5A-1MP electronic psychrometer was procured and installed, replacing a Thunder manually operated relative humidity standard.

A Weinschel Engineering automated power sensor calibration station was added to the microwave calibration facility.

## **5.2 In-Situ Calibration**

In-situ pressure calibration development continued. In-situ pressure procedures were developed and several in-situ pressure calibrations were performed. Work has continued in developing in-situ electrical calibrations that will include power supplies, digital voltmeters, and oscilloscopes.

## **6.0 Equipment Replacement and Updating**

Investigations continued on the replacement of sonic flow nozzles meters with mass flow meters. A test plan was initiated to evaluate flow meters under a variety of conditions. After failing two mass flow meters for not meeting gas flow specification, a third mass flow meter was procured and tested. This unit also demonstrated specification problems at low range flows. Specifying mass flow requirements—and ensuring that vendors can meet them—continues to be more difficult than originally expected. Testing will continue as funding is made available.

A Datron 4808 autocal multifunction calibrator is being procured to allow automated calibration of 6½-digit DVMs. The existing Datron 4700 will be used in an in-situ calibration station that is under development.

A Ruska 4.1 MPa (600 psig) dead weight pressure standard was updated with new hardware and a Ruska 2411 auto prompt converter. The auto prompt program calculates weights and records and prints out calibration data. The update increases the Ruska's pressure range, accuracy, and ease of use.

Additional microwave test equipment, test fixtures, and procedures are being procured to upgrade the microwave calibration system in support of the new Second TDRSS Ground Terminal.

## **7.0 Calibration Procedures and Software Development**

All 250 calibration procedures were reviewed and scheduled for updating. Procedures with safety, hazard waste, or OSHA issues are receiving top priority.

Modifications to the metrology data base are being made to improve the analysis of historical data and the recommendation of calibration interval changes.

The HP Shared Resources Manager server has been replaced with a UNIX server, making it possible to develop new automation software in UNIX. The first software of this type is under development. It will automate the delta pressure calibration station using HP BASIC/UX (UNIX).

## **8.0 Training**

The electrical calibration engineer attended a 5-day NIST-sponsored electrical measurement assurance workshop. The programmer attended a 5-day HP UNIX training session.

WSTF participated in the 1991 National Conference of Standards Laboratories where metrology seminars were attended.

A TQM team was formed and trained in TQM concepts. The team analyzed calibration operations and surveyed customers on services. The team proposed 12 continuous improvement initiatives to be initiated this year.

## **9.0 Certification of Reference Standards**

The following standards were submitted to NIST for calibration, were part of a MAP, or were calibrated by an intrinsic standard (IS).

10 Volt (MAP/IS)	Noise Source	Thomas One Ohm (MAP/IS)
Mismatches	Anemometer	Attenuators
Gage Blocks (IS)	Weight Set	Attenuator Verification Kit
Pulse Generator	PRT (MAP/IS)	

## **10.0 Problem Areas**

Lack of resources to replace high-cost, obsolete calibration systems continued to be a problem.

The cost of NIST calibrations continued to grow at a faster rate than budget increases, so alternative sources which meet NIST-traceability requirements were sought. A commercial calibration facility with intrinsic standards for resistance, voltage, temperature, and dimensional calibrations was located and used to calibrate WSTF reference standards.

Vendors continued to supply equipment that does not meet specifications. One automation project was canceled because a Rosemount temperature controller failed to meet specifications. The project has been placed on hold until a replacement can be researched and procured.

## **11.0 Activities**

### **11.1 Previously Reported Activities**

**Upgrade of Gas Flow Calibration System.** Testing continues to determine the feasibility of upgrading the gas flow calibration system. The plan calls for use of mass flow meters at

9–120 g/s to replace the sonic flow nozzles presently used as standards. The mass flow meters would decrease the calibration uncertainty from 1.0 percent to less than 0.5 percent. Test data is being obtained to verify that NIST traceability can be maintained if the mass flow meters are calibrated using the Flow Tech liquid flow calibration station.

**Microwave Measurement Assurance Program.** A Measurement Assurance Program has been funded for the microwave disciplines of rise time, attenuation, and phase. The MAP will be designed to provide NIST traceability through statistical analysis of MAP data.

## **11.2 Future Activities**

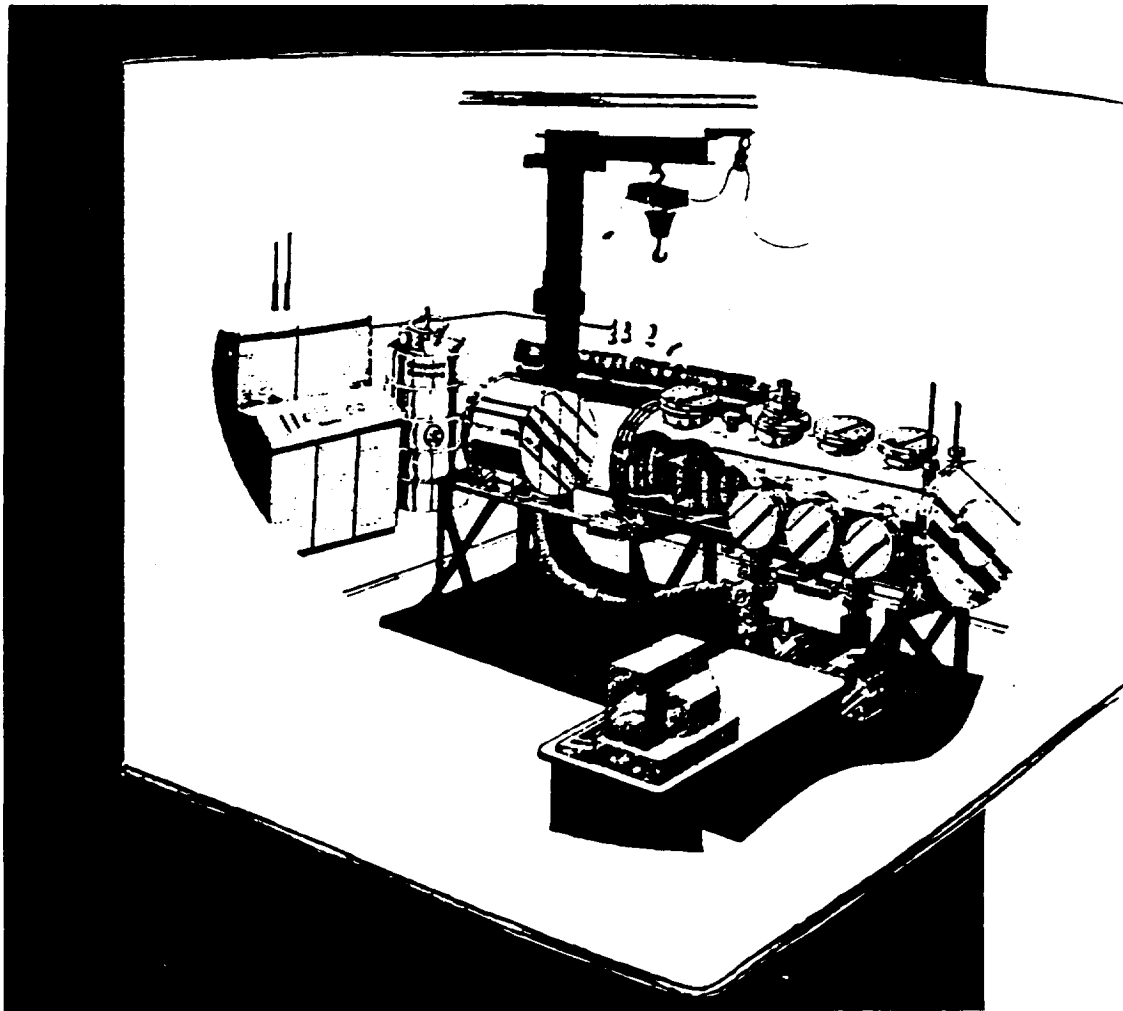
**Transient Pressure Calibration.** Significant requirements for calibration of piezoelectric transducers are expected in the next year. NIST and WSTF have discussed a joint research program and presented a proposal to develop a NIST-traceable capability for transient pressure calibrations.

**Automated Control of Fluidized Temperature Bed.** Software development for the planned automation of thermocouple and PRT calibrations has been delayed. The Rosemount temperature controller that had been procured for this program was rejected and a suitable replacement has not been located.

# EXTRANEOUS MATERIAL



**LOW BACKGROUND  
INFRARED  
CALIBRATION  
FACILITY**



---

**NATIONAL INSTITUTE OF STANDARDS  
AND TECHNOLOGY  
GAITHERSBURG, MARYLAND 20899**



## INTRODUCTION

A facility for the calibration of infrared sources in a low background environment has recently been completed at the National Institute of Standards and Technology. Managed by the Radiometric Physics Division as part of the Center for Radiation Research at NIST,

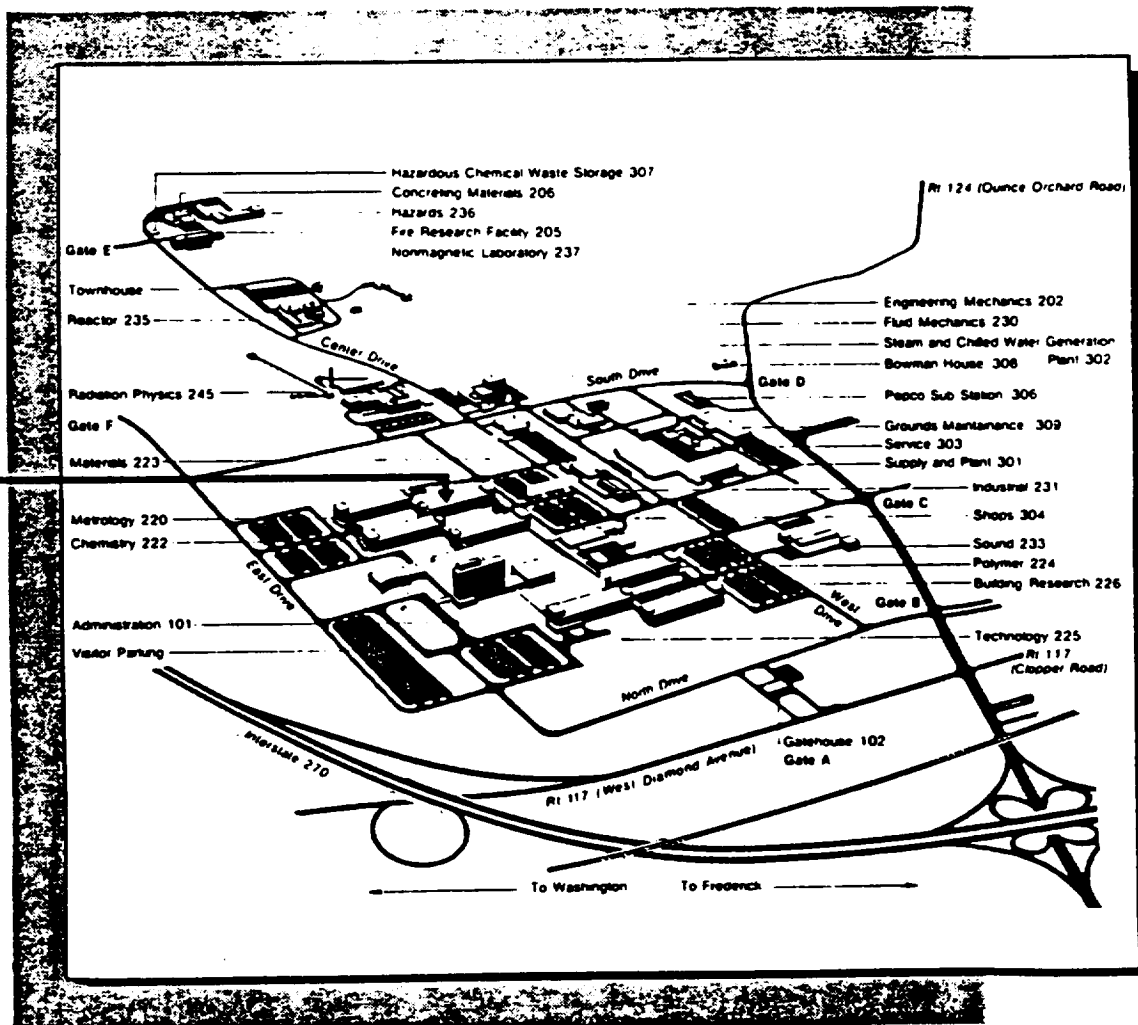
the new LBIR Facility is available to service the user community seeking to characterize black body radiometric sources which need to operate in a Low Background environment. The initial capability is the measurement of total radiant power from a black body with anticipated future improvements

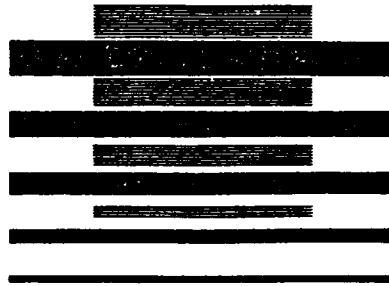
allowing for measurement of spectral and angular distribution of the emitted radiation. The scientists at the facility are willing to consider joint collaborations in experiments which could utilize the features of this system.



## NIST GROUNDS

PHYSICS 221





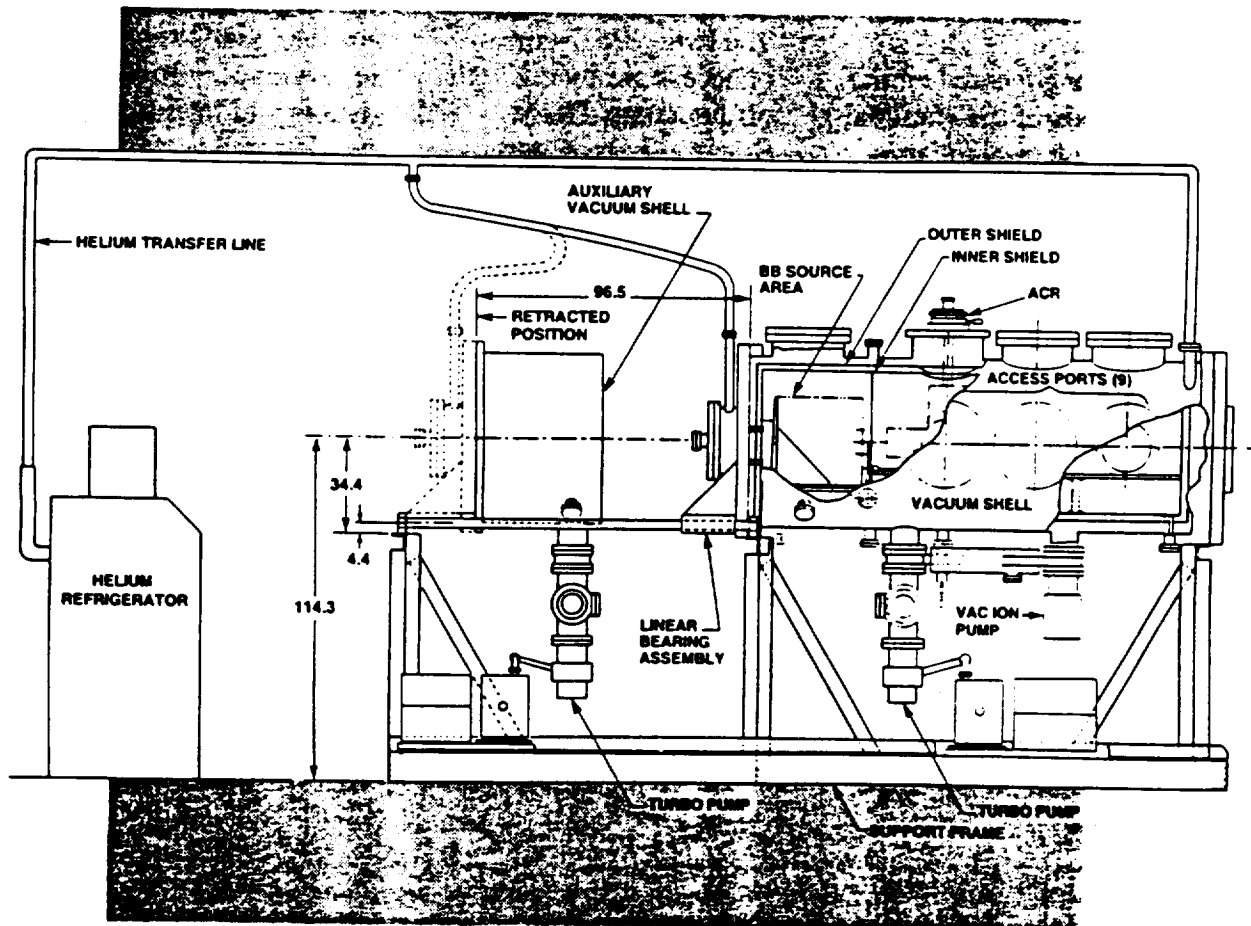
## **LOCATION**

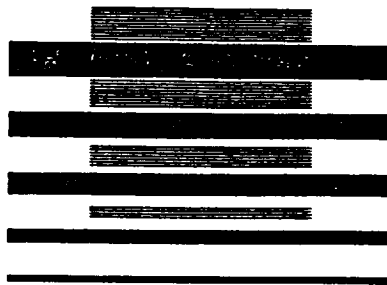
The LBIR Facility is housed in the Physics Building located on the grounds of the National Institute of Standards and Technology in

Gaithersburg, Maryland. The two primary means of access are by car, exit off Interstate 270 at Route 117 West, and by rapid transit to the Shady Grove

Metrorail Station. The Institute provides shuttle service for official visitors and staff from the Metrorail Station to NIST.

# LBIR FACILITY





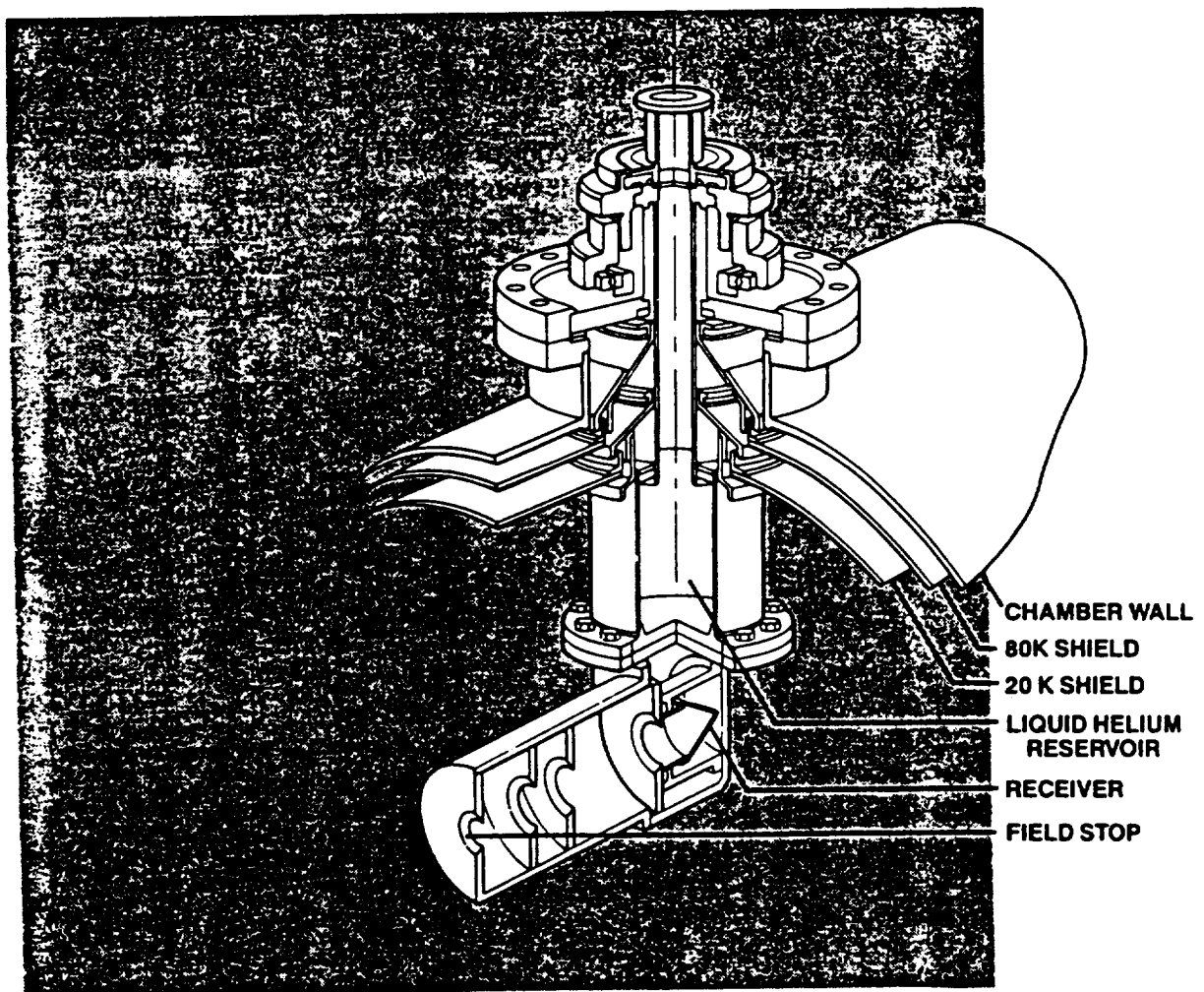
## **FACILITY**

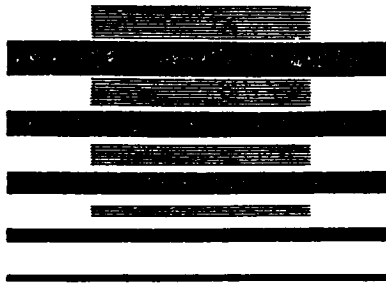
Two full-time NIST staff members are available to operate the LBIR Facility which consists of a large (60 cm diameter by 152 cm long) vacuum chamber surrounded by a soft-wall cleanroom. A low background environment inside the chamber is achieved by cooling internal

cryoshields to temperatures less than 20 K using a closed cycle helium refrigerator system. A sophisticated control system is available to monitor and control all the temperature-critical elements associated with the calibration. Sources of up to 30 cm square can be inserted into the chamber for calibration. The

partial cutaway of the drawing at left shows the relative position of this source area. Also shown is the auxiliary vacuum shell into which the black body source will be placed for initial conditioning and check for vacuum cleanliness.

## CRYOGENIC RADIOMETER





## ACR

Total radiant power from the black body is measured with an Absolute Cryogenic Radiometer (ACR). The ACR has a resolution of approximately one nanowatt as design criteria.

The ACR is shown here mounted into one of three available ports. The vacuum vessel is large enough to accommodate additional elements between the source and the radiometer as it is fitted with a

cooled bench for mounting hardware in the optical path. Additional vacuum ports are available to provide access for various new applications.



## **INFORMATION**

Inquiries regarding scheduling  
for calibrations should be  
directed to:

**National Institute of  
Standards and Technology  
Radiometric Physics Division  
Building 221, Room A-221  
Gaithersburg, Maryland 20899  
Phone: (301) 975-2350**

**L · B · I · R**







# **Metrology and Calibration Working Group Communications**

**16th ANNUAL NASA  
METROLOGY & CALIBRATION WORKSHOP  
Rockville, MD**

**22 April 1993**

**R.E. Martin**

**Jet Propulsion Laboratory  
California Institute of Technology  
Pasadena, California, USA**

---

## **Metrology & Calibration Working Group Communications**

- Internet node is established for e-mail
  - JPL providing host
- Communicate through Internet in two ways
  - E-mail direct to Working Group Member
  - E-mail to entire Working Group membership
- Working Group membership address

**[nasamwg@inst-sun1.jpl.nasa.gov](mailto:nasamwg@inst-sun1.jpl.nasa.gov)**

- This address will reflect messages to entire Metrology & Calibration Working Group membership

## **M&CWG Communications (cont'd)**

- Need e-mail addresses from Working Group members
  - E-mail subscription request to:  

**amark@inst-sun1.jpl.nasa.gov**
  - Your address will then be added to the distribution list
  - Present subscribers
    - **bmartin@inst-sun1.jpl.nasa.gov (Bob Martin—JPL)**
    - **steveb@inst-sun1.jpl.nasa.gov (Steve Bednarczyk—JPL)**
    - **valora@inst-sun1.jpl.nasa.gov (Valora Pirtle—JPL)**
    - **amark@inst-sun1.jpl.nasa.gov (Al Mark—JPL)**
- Working Group registration with Internet Registration Service—Network Information Center (NIC) is being pursued



***BOEING***

WP01

Space Station Freedom Program

**D683-10084-3**

**SYSTEM ENGINEERING AND  
INTEGRATION PLAN  
VOLUME II:  
METROLOGY PLAN**



November 19, 1992

Submitted to: National Aeronautics and Space Administration  
Marshall Space Flight Center  
Contract No. NAS8-50000 (DR SE01)

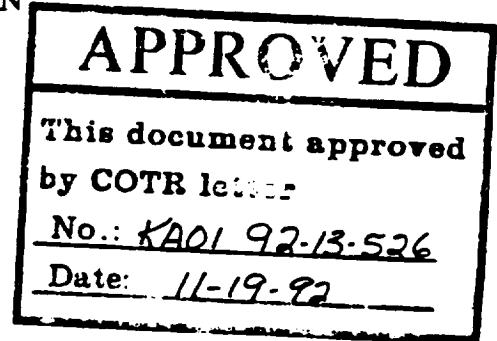


SYSTEM ENGINEERING AND INTEGRATION PLAN

Volume II: METROLOGY PLAN

DR SE01  
(D683-10084-3)

November 19, 1992



Boeing Defense & Space Group  
Aerospace & Electronics Division  
(a division of The Boeing Company)  
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D683-10084-3

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## **ABSTRACT**

The Metrology Plan, DR SE01 (Volume 2), is the current plan for directing all metrology activities on the Space Station Freedom Program Work Package 01 (WP01). It defines the metrology approach, philosophies, criteria, program and process required during the design, Development Testing, Qualification, Acceptance Testing, Prelaunch, Post Landing and On-Orbit phases of the program. This plan is submitted as Volume II of Data Requirement (DR) SE01, Systems Engineering and Integration Plan.

## **KEY WORDS**

Acceptance

Calibration

Development Testing

Measurement

Metrology

National Institute Of Standards And Technology

On-orbit

Post Landing

Prelaunch

Product Assurance

Verification

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## SECTION 1. INTRODUCTION

### 1.1 BACKGROUND

The Work Package 01 (WP01) contract requires that an On-Orbit Quality Activities plan be submitted at Critical Design Review (CDR). The Quality Activities plan is submitted under Data Requirement (DR) QA03. One aspect of the plan addresses on-orbit calibrations. When it became apparent that a separate detailed WP01 calibration plan was required, it was decided that a second volume to the System Engineering and Integration Plan (DR SE01) should be prepared for this purpose. This plan supports the on-orbit and ground calibration requirements of DR QA03.

### 1.2 PURPOSE

This plan provides the metrology approach, philosophies, criteria, program and process. Its primary purpose is the assurance of the long term integrity of the operations and performance of on-orbit systems. This to be accomplished through:

- A. Definition of processes to determine on-orbit out-of-tolerance condition.
- B. Definition of expected intervals between out-of-tolerance condition.
- C. Definitions of repair/replace or calibrate philosophy for each sensor.
- D. Definition of on-orbit calibration requirements.

### 1.3 SCOPE

This plan encompasses the metrology approach and criteria for design, development, qualification, acceptance, prelaunch, post landing and on-orbit instrumentation and sensors.

### 1.4 APPLICABLE DOCUMENTS

Documents for which no revision or date is specified, and are contractual per Contract NAS8-50000 are included in Attachment J-2 (SS-LIST-0001) of the subject contract; and the issue specified therein will apply.

The following is a list of applicable documents used in the preparation of this document.

*1.4.1 Government Documents*

MIL-Q-9858A	Quality Program Requirements
MIL-STD-45662A	Calibration Systems Requirements
SS-SRD-0001E	Space Station Freedom Program Level III System Requirements Document
NMI 5330.9	NASA Management Instruction, Metrology and Calibration
MMI 5300.4G	Marshall Management Instruction, Standards and Calibrations
NHB 5300.4(1B)	NASA Handbook Quality Program Provisions for Aeronautical and Space System Contractors
DR LS03	Maintainability Verification Plan, D683-10123-1
DR OD03	Payload Baseline Operations, Operations Integration and Training Plan, D683-43010-1
DR OP01	Prelaunch/Postlanding Operations Plan, D683-10132-2
DR OP06	Launch Site Support Requirements, D683-10545-1
DR OP15	Orbital Operations Plan, D683-10136-1, Vol 1
DR OP15	Operations Readiness Verification Plan , D683-10136-2, Vol 2
DR OP17	Orbital Operations Requirements Analyses Data, D683-10496-1, Vol 1 & 2.
DR OP19	Operations Maintenance Requirements Specifications, D683-10545-2
DR QA03	On-Orbit Quality Activities Planning, D683-43413-1
DR SV01	Master Verification Plan, D683-10072-1  Habitation Elements Verification Plan, D683-10072-3

U. S. Laboratory Elements Verification Plan  
D683-10072-4

Logistics Elements Verification Plan,  
D683-10072-5

Resources Nodes Systems Verification Plan,  
D683-10072-6

Airlock Systems Verification Plan,  
D683-10072-8

Gas Conditioning Assembly Verification Plan,  
D683-10072-9

DR SV02	Test Verification Documents (many documents)
DR SW02	Software Development Plan, D683-10138
DR SW03	Software Test Plan, D683-10139
DR SW09	Requirements and Procedures, Software Test (Software Test Descriptions) (Many documents)
DR SW10	Software Test Procedures (Many documents)

#### *1.4.2 Other Documents*

##### **BOEING**

D2-5378-1	Measurement and Test Equipment Calibration Procedures – Metrology Engineering
D389-10016-1	Measurement and Test Equipment Metrology Program

#### **1.5 UNISSUED REFERENCE DOCUMENTS**

NHB 5330.9(1A)	NASA Handbook Metrology, Calibration & Measurement Processes Guidelines – Working Copy
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This handbook is not a contractually applicable document. It was presented at a NASA Metrology working group meeting by the authors as a draft, for which comments were solicited. It was stated by the authors that the intent was to issue the document as a NASA STANDARD. So far this has not taken place. The document is included here because it has a great deal of useful information on the metrology process in general.

## 1.6 DEFINITIONS

**ABSOLUTE ERROR OF MEASUREMENT.** The result of a measurement minus the (conventional) true value of the measurand. *Note:* The known parts of the error of measurement may be compensated by applying appropriate corrections. The error of the corrected result can only be characterized by an uncertainty.

**ACCEPTANCE TESTING.** Acceptance tests are those formal tests conducted to assure that the equipment meets contracted or design requirements. Acceptance tests include performance demonstrations and environmental exposures to screen out manufacturing defects, workmanship errors, incipient failures, and other performance anomalies not readily detectable by normal inspection techniques or through ambient functional tests.

**ACCURACY.** The deviation between the result of a measurement and the true value of the measurand. *Note:* The use of the term precision for accuracy should be avoided.

**ACCURACY RATIO:** The ratio of performance tolerance limits to measurement uncertainty.

**ADJUSTMENT:** The operation intended to bring a measuring instrument into a state of performance and freedom from bias suitable for its use, employing only the means at the disposal of the user.

**AUTOMATIC CALIBRATION.** The act of subjecting measurement and test equipment to a predetermined set of conditions by use of programmable test equipment and calibration software or firmware to verify performance specifications.

**CALIBRATION.** The set of operations which establish, under specified conditions, the relationship between values indicated by a measuring instrument or measuring system, or values represented by a material measure, and the corresponding known (or accepted) values of a measurand. *Note:* (1) The result of a calibration permits the estimation of errors of indication of the measuring instrument, measuring system or material measure, or the assignment of values to marks on arbitrary scales. (2) A calibration may also determine other metrological properties. (3) The result of a calibration may be recorded in a document, sometimes called a calibration certificate or a calibration report. (4) The result of a calibration is sometimes expressed as a calibration factor, or as a series of calibration factors in the form of a calibration curve.

**CERTIFICATION.** Certification is a process in which tests and analyses are performed which demonstrate and formally document that the design and manufacturing processes will produce equipment which meets specification requirements in specified operational environments. Certification activities consist of qualification tests and major ground tests as well as other tests and analyses. Metrology certification is the act of designating that standards and measuring and test equipment have been calibrated and meet established

requirements.

**CHECKOUT.** Test activities that verify the readiness of hardware and/or software for its intended use.

**CONFIDENCE INTERVAL.** An interval about the result of a measurement or computation within which the true value is expected to lie, as determined from an uncertainty analysis with a specified probability.

**CONFIDENCE LEVEL.** The probability that the confidence interval contains the true value of a measurement.

**DEVELOPMENT.** Development is primarily concerned with those design evaluation and data gathering activities that support the total design process and provide the engineering database necessary to establish confidence that the hardware and software meets specification requirements and that the manufacturing process produces an acceptable product. The data acquired are used to establish processes, procedures and test levels to support subsequent design, production, verification, maintenance, and checkout activities. Development includes: (1) standard laboratory testing to support material selection; (2) component, breadboard and subsystem testing to identify the failure modes and the effects of environments and combinations of design tolerances on performance; and (3) the acquisition of data from integrated subsystems or system levels to identify operational characteristics and develop ground and flight operational procedures. Development testing is performed with minimum rigor and controls to prove a design approach. Included are tests performed to minimum technical risks and to assist in design engineering activities. These tests encompass material selection, design tolerance verification, and identification of operational characteristics. These test are usually performed by the engineering organization.

**DRIFT (TIME).** The slow variation with time of a metrological characteristic of a measuring instrument.

**FUNCTIONAL TEST.** A test that demonstrates a go/no-go condition with respect to a functional requirement, or to verify a unit meets the performance requirements.

**MAINTAINABILITY DEMONSTRATION.** The process of proving that a component of subsystem satisfies documented maintainability requirements. Normally included with other tests.

**MATHEMATICAL MODEL.** A mathematical description of a system relating inputs to outputs. This description should be of sufficient detail to provide inputs to system analysis studies such as performance prediction, uncertainty (or error) modeling, and isolation of failure or degradation mechanisms, or environmental limitations.

**MEAN TIME BETWEEN OUT OF TOLERANCE.**  $-\text{Usage Hours} / \ln R$ . Where R is the confidence level or measurement reliability as described in Section 3 of NHB 5330.9 (1A).

**MEASURAND.** A physical or electrical quantity, property, or condition to be measured. *Note:* As appropriate, this may be the measured quantity or the quantity to be measured.

**MEASUREMENT.** The set of operations having the object of determining the value of a quantity.

**MEASUREMENT RELIABILITY.** The probability that a measurement attribute (parameter) of an item of equipment is in conformance with performance specifications.

**METROLOGY.** The field of knowledge concerned with measurement.

**PRECISION.** The repeatability or consistency of measurements made with the same sensor. The confidence with which a measurement can be repeated with a given sensor under controlled conditions, or the confidence that two different sensors or techniques can yield the same result. *Note:* The use of the term precision for accuracy should be avoided.

**QUALIFICATION.** Qualification includes activities which demonstrate and document that the design and manufacturing processes produce equipment that meets specification requirements in specified operational environments. Qualification activities are centered around verifying all performance and design requirements invoked on components, subsystems, systems, modules and elements, and the software. Compliance with performance, safety, interface, environmental, and maintainability requirements are included in qualification. Qualification consists of environmental and functional verification activities. Environmental test includes testing to limits of vibration/acoustics, temperatures, pressures, humidity, etc.. Functional test includes testing to limits of performance, such as, flow, pressure, temperature, leakage, voltage, acoustic noise, etc.. Qualification tests are conducted as a part of the verification program to demonstrate that design and performance requirements can be realized under specified conditions.

**RESOLUTION.** A quantitative expression of the ability of a sensor to distinguish meaningfully between the smallest detectable values of the input quantity being measured.

**SENSOR.** A device that responds to either the absolute value or a change in a physical stimulus (heat, light, sound magnetism, pressure, or particular motion) and produces a corresponding reaction, such as a signal. A sensor can be an entire instrument or a part of one that measures a phenomenon.

**SPAN.** The modulus of the difference between the two limits of a nominal range of a measuring instrument. *Example:* nominal range - 10V to +10V: span 20V.

**SPECIFIED MEASURING RANGE / SPECIFIED WORKING RANGE.** The span of measurements for which the error of a measuring instrument is intended to lie within specified limits. *Note:* The upper and lower limits of the specified measuring range are sometimes called the maximum capacity and minimum capacity respectively.

**SPECIFICATION.** A quantitative description of the specified characteristics of an

instrument, device, system, product, or process.

**STANDARDS.** Standards are classified as National, Reference, Transfer, Working and System Standards.

**NATIONAL STANDARDS.** A standard recognized by an official national decision as the basis for fixing the value, a unit of measure in a country. The national standard in a country is usually a primary standard. In the United States, National Standards are established, maintained, and disseminated by the National Institute of Standards and Technology (NIST).

**REFERENCE STANDARDS.** A standard, generally of the highest metrological quality available at a given location, from which measurements made at that location are derived.

**SYSTEM STANDARDS.** Standards that are part of the test equipment and are used to standardize the test equipment or to monitor its uncertainty.

**TRANSFER STANDARDS.** A standard used as an intermediary to compare standards, material measures, or measuring instruments. *Note:* When the comparison device is not strictly a standard, the term transfer device should be used. *Example:* adjustable calipers used to intercompare end standards.

**WORKING STANDARDS.** A standard that calibrated against a reference standard, is used routinely to calibrate or check material measures or measuring instruments.

**TOLERANCE.** The total permissible variation of a quantity from a designated value.

**TRACEABILITY.** The ability to relate individual measurement results to nationally accepted standards through a continuous sequence of controlled measurements within established limits of uncertainty.

**UNCERTAINTY.** An estimate characterizing the range of values within which the true value of a measurand lies. Uncertainty comprises, in general, many components. Some of these may be estimated on the basis of the statistical distribution of the results of series of measurements and can be characterized by experimental standard deviations. Estimates of other components can only be based on experience or other information.

**VERIFICATION.** In the general sense, verification is a process which determines that the space station hardware and software systems meet all design, performance, and safety requirements. The verification process includes analysis, test, inspection, demonstration, or a combination thereof.

In the more specific sense, there are two types or levels of verification activities:

- A. **Hardware/Software Verification Activities**– These activities ensure that the specific hardware/software has been built in accordance with the design, meets established performance requirements, and is free of manufacturing and workmanship defects.
- B. **Design Verification Activities**– These activities ensure that the design of the space station, subsystems, or components as designed meets the requirements defined in contractual specifications. They include both the formal verification activity and the system level verification activity (including hardware/software and interface compatibility). Where verification is not accomplished by testing, analysis, inspection or demonstration shall be performed.



## SECTION 2. APPROACH

### 2.1 METROLOGY PHILOSOPHY

The metrology philosophy is to incorporate measurement performance, safety, reliability, and maintainability in the design. The metrology procedures incorporate the quality assurance policies and procedures defined in SS-SRD-0001E Section 9.0 paragraphs 4.1.4 Planning for On-Orbit Activities and 4.8 Metrology; NASA Management Instruction (NMI) 5330.9, as reflected in Marshall Management Instruction 5300.4G, Standards and Calibration, dated June 25, 1991; and NASA Handbook 5300.4(1B) Chapter 9 Metrology Controls. NHB 5330.9(1A) Metrology, Calibration, & Measurement Processes, Guidelines - Working Copy, has been distributed to the Metrology Plan Development Team members to use as a guide for evaluating implementation of the design requirements for metrology and performance verification. This Handbook is especially useful for evaluating the designs for on-orbit calibration provisions and determining the Mean Time Between Out Of Tolerance (MTBOOT) conditions. The system design and logistics interface is managed to ensure that bidirectional flow of engineering and logistic information/data occurs during all phases of the program. An essential element of the on-orbit logistic support package is the maintenance of the operational systems, subsystems, and equipment. This includes preventive maintenance concepts using performance testing, visual inspection, servicing, and subsystem and system level performance verifications. Where possible, the design is such that sensor recalibrations are not needed, or the recalibration interval is lengthened, or the recalibration is simplified by DMS, or done automatically. A concerted effort is directed to achieving measurement reliability goals without impact to the current design.

Normally an on-orbit out-of-calibration condition of sensors, meters, and transducers results in the replacement of the related ORU. A review of the out-of-calibration condition, by the Space Station Control Center (SSCC) at Johnson Space Center or the Engineering Support Center (ESC) at Marshall Space Flight Center, may result in a determination of the acceptability of operating the ORU in a degraded performance mode or other course of action.

#### *2.1.1 Measurement Quality Requirements Identification*

The measurement quality requirements are objectively defined early in the design activity and drive the measurement process design. A measurement quality requirement is traceable to the decision need that will use the data from the measurement. The measurement is treated as a process with all contributing uncertainty sources identified. The uncertainties reflect a realistic representation of the process so that the process uncertainty is meaningful. Measurement parameter tolerances and measurement risks (confidence levels) are defined to match system and/or component tolerances and operational reliability. When an out-of-tolerance condition is expected to occur within the 30 year life of the station, the unit is identified as a Limited Life Item for inclusion in the operations maintenance plan. The measurement process design is documented with an auditable content directly usable during the operational phase.

## 2.2 FAULT DETECTION AND ISOLATION PHILOSOPHY

Fault Detection and Isolation (FDI) is addressed here to make the distinction between FDI and metrology. The System Requirements Document (SRD) requires Boeing to make operational and FDI data available to the ground. Automatic on-board detection and reconfiguration is required for failures that cause loss of a time critical (Category 1,1c,2s) function. These requirements imply a need for sensor accuracy sufficient to meet specified detection and false alarm rates. Ground based software will be programmed to provide compensation for predictable and known sensor drifts. Ground based analysis is used to detect unpredictable sensor drift and adjust the software to compensate, when possible. However, this process always yields an increased uncertainty for the measurement, because the instrument has, in effect, been recalibrated with something of less accuracy than the original calibration standard. If the reference drifts, this uncertainty grows with time. There is not much to be gained from correction of unpredictable drift unless a cross check can be performed with a statistically significant number of instruments, which is not the case in most applications. Cross checks are of greater value, however, for determining when an instrument has drifted outside the allowable tolerance band. When this occurs it will be replaced or calibrated as required by corrective maintenance. The failure of a single FDI sensor will not cause the loss of a category 1, 1c, or 2s function.

## 2.3 PACKAGING AND MAINTENANCE ACCESS PHILOSOPHY

ORUs are designed to allow ease of removal and replacement. If a sensor goes out of calibration by drifting or loss of accuracy to a point of subassembly degradation, the failure is detected and an ORU replacement action decision is made by the SSCC or ESC in accordance with Test, Operations, and Maintenance Requirements and Specifications (TOMRS), DR OP19.

## 2.4 SAFETY PHILOSOPHY

ORUs are calibrated prior to delivery to Kennedy Space Center (KSC). If metrology/performance verification procedures are conducted on-orbit, with energized equipment, it shall have been assessed, on the ground, to be safe, prior to on-orbit implementation.

## 2.5 RELIABILITY PHILOSOPHY

The relationship of the Failure Mode and Effect Analysis (FMEA) to calibration is through the resultant effect on the item, subsystem, system and the crew/station. Credible equipment out-of-tolerance conditions are identified as a failure mode in the FMEA, along with the associated local, subsystem, system, and station/crew effects. Detection methods are also identified in the FMEA, DR RE10.

Measurement reliability targets are met through the measurement process design. Reliability analysis of the design identifies uncertainty growth processes and appropriate

controls to satisfy these measurement reliability targets. A measurement process yielding data with error greater than the specified uncertainty tolerance is a failure mode. Preventing failure requires control of uncertainty growth by performing calibrations with possible adjustments within the tolerance limits. Measurement systems are made congruent with ORUs when possible to minimize calibration actions which do not involve ORU changeout. Measurement systems should be designed to have an in-tolerance life that exceeds the ORU life where possible.

Hardware for which an out-of-tolerance condition is expected to occur within the 30 year life of the station is identified as a Limited Life Item, in accordance with DR RE07. Data in DR RE07, includes the identity of the item, life limiting characteristic(s), recommended frequency of replacement/ calibration, and the allowable number of calibrations.

Out-of-tolerance conditions, caused by drift, typically involves a slow degradation, as such it generally does not constitute a threat to system operability unless the drift goes undetected. Undetected drift does, however, represent a potentially significant common cause failure mechanism of redundant equipment. Drift is generally detected via comparison of the parameter against a specified threshold or via system performance trending analysis, the latter being more desirable, since system functional failure can be prevented via scheduled intervention (removal and replacement/calibration, performance verification, software adjustment, etc.).

## 2.6 MAINTENANCE PHILOSOPHY

Metrology/performance verification on-orbit is considered a maintenance action. The design goal is that calibrations by the crew on-orbit are to be reduced or avoided if possible except in cases where the trade-off of equipment and crewtime to calibrate versus equipment and crewtime to replace prove beneficial. If on-orbit calibration is required the maintainability, logistics, and orbital support documentation addresses the required activities.

## 2.7 USER PAYLOAD CALIBRATION PHILOSOPHY

User payloads are calibrated by the user prior to launch. WP01 is making no provisions for recalibration of user payloads on orbit.

## 2.8 WP01 VERIFICATION PLANS

The Verification Plans are addressed here since the composite WP01 verifications are described in them. The WP01 Master Verification Plan and the subtier plans are traceable to the Level II verification documentation. Verification plans for software verification and validation (DR SW Series) and materials and processes verification are documented separately and are discussed in Paragraph 2.9 of this document.

The base program verification requirements including derived requirements, based upon the SS-SRD-0001 design and performance requirements are developed for WP01 by the Systems Engineering organization. These requirements are documented in DR SV02 and imposed upon the responsible verification organization. Objective data are obtained during the verification process to validate the measurement process design and reliability analysis, and to verify that measurement requirements of uncertainty limits and confidence limits are met during the specified operational period, including extrapolation of the available data set to a 30 year operational life without calibration. The processes for implementing the WP01 verification requirements are described in the following eight DR SV01 verification documents:

D683-10072-1 WP01 Master Verification Plan introduces the master plan for implementing the WP01 Verification Program and provides the approach and guidelines to be applied during the verification process. The plan also describes the database and traceability system which controls the implementation process and provides assurance that all design/performance and verification requirements are satisfied. Paragraphs 3.3 and 3.4 address the design performance and operations considerations for the 30 year life by Space Station Freedom.

D683-10072-2 Payload Interface Verification Plan addresses the plans for verifying the interfaces between the payloads and WP01 hardware.

D683-10072-3 Habitation Elements Verification Plan contains the verification plans for ensuring that the Habitation Elements (A & B) design/space performance requirements are satisfied and that the Habitation Elements hardware performs as required. The document also addresses the plans for implementing and controlling the Habitation verification process.

D683-10072-4 U.S. Laboratory Elements Verification Plan contains the verification plans for ensuring that the U. S. Laboratory Elements (A & B) design/performance requirements are satisfied and that the U. S. Laboratory hardware performs as required. The document also addresses the plans for implementing and controlling the U. S. Laboratory verification process.

D683-10072-5 Logistics Elements Verification Plan contains the verification plans for ensuring that the Logistic Elements design/performance requirements are satisfied and that the element hardware performs as required. The document addresses the plans for implementing and controlling the Logistic Elements verification process.

D683-10072-6 Resource Nodes Systems Verification Plan contains the verification plans for ensuring that the Node Elements design/performance requirements are satisfied and that the element hardware performs as required. The document address the plans for implementing and controlling the Node verification process.

D683-10072-8 Airlock Systems Verification Plan contains the verification plans for ensuring that the Airlock design/performance requirements are satisfied and that the element hardware performs as required. The document addresses the plans for implementing and controlling the Airlock verification process.

D683-10072-9 Gas Conditioning Assembly Verification Plan contains the verification plans for ensuring that the Gas Conditioning Assembly design/performance requirements are satisfied and that the component hardware performs as required. The document addresses the plans for implementing and controlling the Gas Conditioning Assembly verification process.

## **2.9 SOFTWARE DOCUMENTATION**

The software development and verification plans are located in DR SW02 Software Development Plan, DR SW03 Software Test Plan, DR SW09 Requirements and Procedures Software Test (Software Test Descriptions), and DR SW10 Software Test Procedures. Software includes verification of on-orbit detection of out of tolerance conditions.

- A. DR SW02.** Provides details relative to activities and resources for developing software, including support software.
- B. DR SW03.** Defines the type of software testing, test schedules, and test management procedures to be used. This document includes both independent verification and validation and acceptance testing.
- C. DR SW09.** Itemizes the tests used to confirm that the product meets the software requirements. This includes verification, validation and acceptance test requirements for the test procedures.
- D. DR SW10.** Provides the detailed procedures and test specifications necessary at all levels of testing prior to acceptance of the software.

## **2.10 INTEGRATED LOGISTICS SUPPORT DOCUMENTATION**

Once a firm requirement for system/ equipment calibration is established, these requirements are documented in the Logistics Support Analysis Records(LSAR) database. Step by step maintenance procedural steps are documented and the support resources requirements accomplish the maintenance task. This is source data for the following logistic documents.

- A. DR LS01 – Maintenance Plan –** Define WP01 Maintenance Program including maintenance concept, planning and detailed maintenance plan development.
- B. DR LS08 – Recommend Spares List –** Documents spares required to support maintenance implementation. Document used during provisioning conferences and will become the authority to procure WP01 spares.
- C. DR LS11 – Operatins and Maintenance Instructions –** Formal maintenance procedures to be used by crew and/ or ground personnel to perform maintenance.
- D. DR OP08 – Special Handling and Transportation requirements per MMI6400.2.** Includes shipping container and packaging data, calibration items will be clearly marked outside the shipping containers.

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## SECTION 3. METROLOGY CRITERIA

### 3.1 DESIGN REQUIREMENTS

The metrology philosophy dictates that in the design phase adequate attention is directed to achieving the measurement reliability goals. Analysis of the design will be conducted that identifies all error sources, develops an error model, evaluates total measurement uncertainty, evaluates uncertainty growth processes, selects appropriate measurement reliability models, and verifies that measurement reliability targets are met. The methodologies and techniques to accomplish this task are provided in the draft working copy of NHB 5330.9 (1A) and are incorporated in the metrology process described in Appendix B (Metrology Process).

### 3.2 DEVELOPMENT TESTING, QUALIFICATION AND ACCEPTANCE

The sensor and instrumentation calibrations conducted during the development, qualification, and acceptance phases are considered to be straight forward, laboratory calibrations, traceable to National Institute of Standards and Technology (NIST) recognized standards. The calibrations are conducted in accordance with the Boeing Huntsville "Measurement and Test Equipment Metrology Program" (MTEMP) documented in D389-10016-1. The MTEMP program includes requirements of MIL-Q-9858A Quality Program Requirements, MIL-STD-45662A, Calibration Systems Requirements and SS-SRD-0001 Section 9, Paragraph 4.8, Metrology Control. The MTEMP program provides definitions of terminologies, supporting documentation, procedures, certificates, reports, and instructions to personnel on how to operate the MTEMP, especially during the development, qualification and acceptance phases. These are available to authorized customer representatives for audit purposes upon request.

Sensors incorporated in the design of Space Station Freedom equipment are calibrated in accordance with the above documents, prior to installation into the equipment. During the development testing activities, special instrumentation is used to obtain engineering design data and qualification and acceptance data, and to verify the MTBOOT calculations where possible. This special test instrumentation is calibrated in accordance with the Boeing Huntsville Measurement and Test Equipment Metrology Program, as summarized in paragraph 4.1.1 of this plan. Calibrated ORU sensors are used during the qualification and acceptance testing.

### 3.3 PRE-LAUNCH

There are presently no known requirements for calibration at KSC, following the final acceptance testing at MSFC. Each sensor is calibrated and the subsystem, system, and elements have satisfied the performance verification requirements as part of manufacturing assembly and checkout processing at MSFC to support acceptance test and KSC processing. If a calibrated system fails a pre-launch test or fails as a result of a metrology fault, the sensors calibrations are checked, the system is repaired, recalibrated, and retested in accordance with the acceptance metrology and performance verification test procedures.

The Launch site verification and support requirements will be transmitted to KSC via the Operational Maintenance Requirements Specifications D683-10545-2 (DR OP19) and Launch Site Support Requirements D683-10545-1 (DR OP16).

Operational Readiness Verification is supported at the operational sites and facilities to verify readiness prior to flight article launches. Typical functions to be certified in the operational readiness verification includes:

- A. Flight Elements
- B. Flight & Ground Operational Support Equipment.
- C. Ground Processing & Flight Support Equipment.
- D. Flight Operational/Support Facilities.
- E. Procedures/Software
- F. Data and Command/Control Links

Additional details on the plan and procedures for operational readiness verification are contained in the following documents:

- (1) Prelaunch/Postlanding Operations Plan D683-10132-2, (DR OP01)
- (2) Orbital Operations Plan D683-10136-1(DR OP15)
- (3) Payload Baseline Operations, Operations, Integration & Training Plan, D683-43010-1 (DR OD03)

### 3.4 ON-ORBIT

The design goal is that ORUs shall require little or no astronaut intervention for on-orbit metrology. Subsystem and system level preventive maintenance includes all scheduled maintenance actions performed to retain a subsystem or system in a specified condition. Scheduled maintenance includes the accomplishment of periodic inspections, condition monitoring, critical item replacement, and subsystem or system level performance verifications and calibrations as required necessary to insure the correction of incipient failures before they occur. The schedule interval is based on equipment usage (operating hours, cycles) or elapsed calendar time (hours, days, weeks, months, etc.). Test, Operations, and Maintenance Requirements and Specifications (TOMRS) contain these maintenance requirements. The Instrumentation Program and Command List, D683-10522-1, documents the calibration intervals for instrumentation connected to DMS Multiplexer/Demultiplexers (MDMs). The calibration intervals will be defined in the vendors instrumentation specifications.

On-Orbit assembly activation and checkout procedures are verified, as part of the element acceptance procedures. On-orbit assembly and contingency sequence analyses are verified per D673-10496-1, Orbital Operations Requirements Analyses Data (DR OP17 vol 1). The on-orbit first time verification shall be limited to subsystem/systems that are not mission or safety critical. Such verification shall require Space Station Control Board approval. Critical Category 1, 2, and 2S subsystems/systems shall be verified prior to launch. On-orbit verifications are contained in documents D683-10136-1, (DR OP15 vol 1), Orbital Operations Plan, D683-10136-2 (DR OP15 vol 2) Operations Readiness Verification Plan and in D683-10496-2 (DR OP17 vol 2), Orbital Operations Analysis Data which will be developed for each element launched for the life of the Space Station. The IP&CL will contain the on-orbit hardware and software signal definitions to support the verification process. The IP&CL documents the signal type and calibration coefficients that will be required for functional and verification testing.



### 3.5 POST LANDING

ORUs that return from orbit, based on routine maintenance requirements or an out of calibration condition, are returned to Boeing or the subcontractors for a post-calibration check prior to being refurbished. After refurbishment, a complete calibration is performed before the unit is returned to service. ORUs that return from orbit, due to a failure, are returned to Boeing or the subcontractors for determination of the cause of the failure.

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## SECTION 4. METROLOGY PROGRAM IMPLEMENTATION

### 4.1 GROUND METROLOGY

#### 4.1.1 *Development testing, qualification, and acceptance*

Sensors that are designed into WP01 Space Station equipment are calibrated, prior to installation into the equipment, to satisfy the requirements of the SRD or the Envelope Drawings and the Metrology Plan. The measuring systems used for testing and verification are calibrated in accordance with the following paragraphs.

##### 4.1.1.1 *Metrology Standards*

Standards are maintained for calibrating M&TE and other standards. Uncertainty, stability, range and resolution are considered when selecting equipment for use as a standard. The uncertainty of calibration standards is established through an echelon of standards whose accuracy is traceable to the NIST by the Boeing Company.

#### A. Class Of Standards

The echelon of standards consists of the following standard classes.

##### (1) Class A Standards

Class A standards are the highest echelon of measuring equipment within the Boeing Company and are in the custody of the Boeing Metrology Laboratory (BML) in Seattle, Washington. These standards are periodically checked, directly or through a precise intercomparison with the legal standards maintained by the NIST, or with other natural standards authorized for this purpose.

##### (2) Class B Standards

Class B standards are the second highest echelon of measuring equipment within the Boeing Company and are in the custody of equipment calibration laboratories. There are two basic categories of equipment within this classification.

- a. **Class B Secondary Standards:** These standards are considered as the reference standards for the Boeing metrology program and are in the custody of the Huntsville Metrology Laboratory (HML). These standards are periodically calibrated from or through a precise intercomparison with the Class A standards defined above or with other basic standards authorized for this purpose. In the event that the Boeing Metrology Laboratory (BML) does not have the capability to calibrate a given Class B Secondary standard, the standard may be calibrated by another facility, such as the manufacturer, provided the facility meets the requirements of MIL-STD-45662A.
- b. **Class B Measurement Standards:** These standards are considered as the transfer standards for the Boeing Huntsville metrology program and are in the custody of the HML. These standards are periodically calibrated from or through a precise intercomparison with the Class B Secondary standards or with other basic standard authorized for this purpose. In the event that the HML does not have the capability to calibrate a given Class B Measurement Standard, the standard may be calibrated by another facility provided the facility meets the requirements of MIL-STD-45662A.

**B. Class C Equipment**

Class C equipment is the third echelon of measuring equipment within the Boeing Company. Class C equipment is calibrated from or through a precise intercomparison with the Class B standards or with other standards authorized for this purpose. In the event that the HML does not have the capability to calibrate a given piece of Class C equipment, the equipment may be calibrated by another authorized facility that meets the requirements of MIL-STD-45662A.

**4.1.1.2 Environmental Controls**

Environmental conditions such as temperature, humidity, vibration, cleanliness, or other controllable factors, are considered and controlled or compensated for to the extent necessary to assure measurement accuracy. The HML is responsible to determine the environmental requirements. Correction factors applied at the time of calibration are documented on the calibration certificate, calibration report, or equipment deviation label. Controlled parameters are monitored as required to ensure that tolerance limits are not exceeded.

**4.1.1.3 Calibration Intervals**

The calibration interval is the length of time, expressed in days, months or years during which equipment items are reasonably expected to perform within the calibrated

performance specifications. Standards and M&TE are calibrated at periodic intervals to assure measurement accuracy. Calibration intervals are selected to prevent out-of-tolerance conditions, yet provide extended availability.

**A. Initial**

The initial calibration interval is based on one or more of the following criteria:

- (1) D2-5378-1 Measurement and Test Equipment Calibration Procedures – Metrology Engineering.
- (2) The sensor manufacturer's recommendations and supporting data.
- (3) Government Technical Orders.
- (4) History and performance of the family of like items.

**B. Interval Adjustments**

The metrology program provides for the adjustment of calibration intervals based on the calibration history of the sensor or M&TE. As the equipment progresses through development tests, qualification, and acceptance testing, data are compiled to support the determination of possible interval adjustments.

**C. Extensions**

Sensors and M&TE that are assigned a periodic calibration interval may have the calibration due date extended. The extension is made at the discretion of the Metrology Manager and is permitted if calibration would adversely affect a test or if loss of use of the equipment results in the delay of or prevents a critical task accomplishment by a schedule completion date. An extension is granted based on the calibration history of the equipment.

**4.1.1.4 Recall**

The Metrology Program provides for a mandatory recall system which identifies sensors to be recalibrated on or before the interval expiration date. The user is notified of the calibration due date through the calibration interval label and an overdue report. Sensor users are responsible for assuring that sensors are submitted for recalibration prior to the expiration date and for not using sensors that are overdue, without an approved extension.

**4.1.1.5 Metrology Procedures**

Metrology procedures are developed and used to provide adequacy and consistency in the calibration of sensors, M&TE, and standards. These procedures are the working level instruction for calibration of any given piece of measuring equipment. They consist of any combination of Boeing developed procedures, manufacturer's calibration instructions,

Government-Industry Data Exchange Program (GIDEP), or Technical Orders. They define the calibration standard to be used and the standard accuracy required, the required parameter, range and the required accuracy of the item being calibrated.

#### *4.1.1.6 Out-of-tolerance Evaluation*

The Metrology Program provides for the collection of out-of-tolerance data and the evaluation of these data to maintain the adequacy of the program. Out-of-tolerance data are collected through the use of tolerance codes and data records. An item submitted for calibration is compared against a known standard and is then assigned a tolerance code depending on the condition of the item. The codes used are listed below:

- A. Code O – An out-of-tolerance condition which could have caused a product to be accepted beyond the allowable manufacturing limits or caused the generation of erroneous data. Malfunctioning, inoperative, or damaged equipment are not Code O candidates.
- B. Code P – Equipment submitted in a malfunctioning, inoperative, or damaged condition.
- C. Code I – Equipment checked in tolerance when submitted for recalibration.
- D. Code N – New equipment received for initial calibration.

Upon completion of the calibration, the assigned tolerance code is entered into the records system for history and data collection purposes. When equipment being calibrated is found to be significantly out-of-tolerance (two times the tolerance) an Out-Of-Tolerance Notification form is initiated by the Metrology Laboratory. The form identifies the out-of-tolerance equipment, documents the out-of-tolerance data, and provides for corrective action by the functional organization using the equipment. A copy of the form is sent to Quality Assurance. The out-of-tolerance condition is investigated by the functional organization to determine possible adverse impact on product integrity, isolate any affected product, and determine required corrective action. The completed form is returned to the Metrology Laboratory and is kept for a minimum of two years. An item returned for calibration in an out-of-tolerance condition three consecutive times is withheld from further use until positive corrective action can be taken. The evaluation of this item includes, but is not limited to the following:

- (1) The adequacy of the equipment for the required measurements, recalibration interval, and environment in which it is used.
- (2) The measurement and test procedures.
- (3) The adequacy of the standards and procedures used to calibrate the equipment.

- (4) Special repair or maintenance considerations.
- (5) Reduction of the equipment calibration interval.
- (6) Possibility of modifying or scrapping the equipment.

The corrective action taken is recorded on the data record and entered into the history file.

#### ***4.1.1.7 Maintenance And Repair***

The Metrology Program provides for the assurance of proper maintenance and repair of all calibrated equipment. Calibrated equipment receives maintenance and repair as a part of preventive maintenance and/or repair at the time of calibration. Repair is also provided if the equipment is damaged or fails during the calibration interval. The calibrating agency is responsible to assure equipment is properly recalibrated after repair or modification.

#### ***4.1.1.8 Storage, Handling, And Transportation***

The using organization in custody of calibrated equipment are responsible to store, handle, and transport the equipment in a way that does not adversely affect the calibration of the equipment. Equipment requiring special handling shall be marked as such and shall be shipped in containers so marked. Packaging, handling, storage, and transportation of program critical hardware is documented LAW DR OP08.

##### **A. Storage**

Measurement equipment is stored in accordance with the manufactures recommendations or good warehousing practices. Equipment storage areas provide a protected environment which is clean, dry, and environmentally controlled, if necessary and in suitable containers, if required. Equipment prone to corrosion will be protected with a protective coating prior to storage. Equipment that is stored is labeled with a Certification Expired label. Stored equipment is recalibrated prior to use, after being recalled from storage.

##### **B. Handling**

Measurement equipment is handled in a manner that neither damages the equipment nor adversely affects the calibration. Manufacturer's recommendations and good handling practices are observed. Special handling instructions over and above normal handling precautions are identified and attached to the equipment and container. Equipment that is damaged or when the calibration is thought to be compromised as a result of handling, is returned to the calibrating agency for repair and/or recalibration.

##### **C. Transportation**

Measurement equipment is transported or shipped in a manner to protect it from adverse weather, vibration, physical shock, and handling damages. In-plant transportation is on carts with low pressure pneumatic tires and/or with shock absorbing materials between the cart and the equipment. Vehicles used for outdoor transportation are equipped with pneumatic tires, padded shelving or flooring, and tie down straps as required. Protection is provided from adverse weather conditions and precautions are taken to prevent damage from thermal shock and condensation when equipment is moved from one temperature range to another. Transportation routes and speeds are tempered to account for floor and ground conditions to reduce vibration, physical jarring, and shock. Equipment that is shipped to other facilities is packaged in accordance with the manufacturer's recommendation or good packaging practices to assure that the equipment is properly protected during shipment. Instances of improper handling, storage, or transportation are reported to the appropriate manager for corrective action.

#### ***4.1.1.9 Source Quality Provisions***

Boeing Huntsville subcontractors, which supply services or products to the company are audited to assure compliance with the necessary requirements. Records of the audits performed by Quality Assurance are maintained by Quality Assurance. Calibration sources, other than the NIST or a Government Laboratory, are audited to assure that they are capable of performing the required service to the satisfaction of the requirements. Calibration certificates from sources other than the NIST or a Government Laboratory attest to the fact that the standards used to conduct the calibrations have been compared to the National Standards, either directly or indirectly, and at the planned intervals.

#### ***4.1.1.10 Metrology Facilities***

Facilities, other than those of the HML, are used to perform calibrations when the HML lacks the necessary standards, equipment, facilities, or skills. The HML management will determine the need to use other calibration facilities.

#### ***4.1.2 Pre-Launch***

Pre-Launch sensor metrology activities, if required, are controlled by the same procedures as those outlined in paragraph 4.1.1 Development Testing, Qualification, and Acceptance. There are presently no known requirements for metrology at KSC after the final acceptance testing at MSFC. Each sensor is calibrated and each element, subsystem, or system performance is verified as part of manufacturing assembly and checkout processing at MSFC to support acceptance test and KSC processing. If an ORU fails a pre-launch test or fails as a result of a metrology fault, an ORU sensor metrology and performance verification check is conducted prior to the ORU being repaired, recalibrated, and retested in accordance with the acceptance metrology and test procedures. OMRS contain maintenance specifications relative to metrology and performance verifications.

#### ***4.1.3 Post Landing***

The Post Landing metrology activities are controlled by the same procedures as those outlined in paragraph 4.1.1 Development Testing, Qualification, and Acceptance. ORUs that



return from orbit, based on routine maintenance requirements or an out of calibration condition, are returned to Boeing for a post-calibration check prior to being refurbished. After refurbishment, a complete calibration is performed before the unit is returned to service. ORUs that return from orbit, due to a failure, are returned to Boeing for determination of the cause of the failure.

## 4.2 ON-ORBIT METROLOGY

The current goal is to not conduct calibrations on-orbit except in cases where the trade-off of equipment and crewtime to calibrate versus equipment and crewtime to replace proves beneficial. The combination of the FDI and periodic subsystem and system performance assessments provide confidence that the Space Station equipment is operating within acceptable limits. The FDI subsystem and system performance assessments are successfully demonstrated to meet the design requirements during the development and qualification phases. On-Orbit metrology and performance verifications are considered maintenance activities and are contained in TOMRS.

NHB 5330.9 (1A) paragraphs 3.4.1 and 3.4.2 provide a good summary of on-orbit calibration requirements and measurement statistical process control for on-orbit hardware and are summarized here. This section is applicable to all flight sensors, transducers, and instrumentation. Ground based hardware and software to support on-orbit operation is also covered by this section. The ground based metrology section covers Flight Support Equipment (FSE) and ground based metrology equipment.

The objective of calibration is to control the uncertainty growth of the measurement processes. Measurement processes are performed to monitor and control the growth of space system hardware performance parameters to within established limits. Performing these functions to support the process with reduced need for human intervention during on-orbit missions is going to be especially difficult. Calibration requirements created by long term orbiting missions pose special problems.

The design of ORUs and subsystems that require periodic calibration or evaluation should consider providing functional and physical metrology architecture designed to accommodate techniques and methodologies that will permit calibration and/or evaluation. The architecture should utilize self-calibration, self-test, self-monitoring, and stable reference standards technologies to reduce and facilitate on-orbit metrology control.

A requirement for long calibration intervals means that high MTBOOT design targets will result. These will be difficult to meet unless the designs are very simple, and reduce the number of components used. For those measurement systems whose calibration intervals are estimated to be shorter than the mission duration requirement, special in-place calibration or interval extension schemes should be attempted. One or more of the following are suggested for consideration:

- A. Using earth-to-space-to-earth comparison signals.

- B. Replacing unstable measurement system components with easily installed, small, modular, freshly calibrated units.
- C. Designing in compensating measurement circuitry to improve reliability/MTBOOT.
- D. Using alternative or multiple measurement sensors with comparison devices and statistical process control schemes to improve uncertainty.
- E. Using built-in measurement standard references at selected points in the operating range.
- F. Using carefully characterized astronomical artifacts as intrinsic type measurement references such as thermal, radiation, intensity, and noise references.
- G. Using higher accuracy (>10:1) measurement processes to compensate for increasing uncertainty over time such that the calibration interval matches the time where uncertainty growth has reached a point equal to a 10:1 process before re-calibration is due.
- H. Tightening end item hardware tolerance requirements to create more conforming hardware that can tolerate the lowered confidence levels generated by the increasing uncertainty over time of the measurement process.
- I. Measuring end items more frequently to assure higher confidence that parameter growth beyond performance limits is detected earlier and that a higher population of end items are operating well within tolerances when deployed.
- J. Employing measurement statistical process control.

All of these and any other schemes that can be devised should be considered to implement on-orbit calibration support, remembering that all measurement systems require complete calibration at some point to assure adequate continued performance.

So called self-calibration or self-test systems are useful, though they are rarely substitutes for complete periodic calibrations. They serve mainly as interval expanders or limited range stop-gap devices. Statistical Process Control (SPC) is a tool to analyze results and permit better decisions to be made. Ultimately, to ensure that any standard/instrument is "in calibration" requires comparison to a known representation of the same unit.

Measurement assurance support is customarily viewed as a process in which the accuracy of a measuring instrument or system is maintained over its life cycle through either periodic calibration or testing. For items that are remotely operated and monitored, such as those deployed in on-orbit environments, periodic calibration or testing is considerably more difficult than with terrestrial applications. In certain applications, such as deep space probes, periodic calibration is next to impossible. In such cases, the use of SPC methods may be advisable.

SPC methods enable the estimation of measurement parameter biases and in-tolerance probabilities through statistical intercomparisons of measurements made using closed sets of independent measuring attributes. The number of attributes in a set may be few or many. The set may include both calibrating units and units under test in either one-to-many or many-to-one configurations.

In traditional calibration and testing, the calibrators are ordinarily required to be intrinsically more accurate than the units under test. Accordingly, measurements made by calibrators are held in higher regard than measurements made by units under test. If a calibrator measurement shows a unit under test to be out-of-tolerance, the unit under test is considered at fault. In making statistical intercomparisons, on the other hand, the SPC methods do not distinguish between calibrators and units under test. Measurement intercomparisons provide bias and in-tolerance probability estimates for units under test and calibrators alike. Consequently, the SPC methods can be employed to evaluate the status of check standards as well as M&TE workload items.

Check standard and M&TE recalibrations may be performed on an attribute set without recourse to external references, if SPC methods are applied under the following conditions:

- (1) The measuring attributes in the set are statistically independent.
- (2) The attributes in the set exhibit sufficient variety to ensure that changes in attribute values are uncorrelated (i.e., tend to cancel out) over the long-term.
- (3) Drift or other uncertainty growth characteristics of the attributes in the set that have been defined prior to deployment.
- (4) The attributes in the set have been calibrated or tested prior to deployment.

If these conditions are met, application of the SPC methods can serve to make payload measuring systems somewhat self-contained.

#### **4.2.1 Metrology Standards**

The current design philosophy is to not do calibrations on-orbit except in cases where the trade off of equipment and crew time to calibrate, versus equipment and crewtime to replace, proves beneficial, therefore, generally eliminating the need for external metrology standards and the resulting impact on the logistic system. There are some components of the (ECLSS) that require the use of consumable fluids for a pre-operational check. These fluids are of a known composition, concentration, and quantity and are brought up to the Space Station on each resupply flight. The need for other metrology standards depends on future design configurations, and the results of trade-offs to be performed under the metrology task. (See Appendix B-Metrology Process)

##### **4.2.1.1 Traceability To NIST**

Any standards used on-orbit, including the ECLSS fluid standards, are traceable to the NIST recognized standards.

#### **4.2.1.2 Class Of Standards**

If standards are used on-orbit they are of the NASA Working Standard class as defined in NMI 5330.9A, paragraph 3.h.(4).

#### **4.2.2 Environmental Controls**

On-orbit metrology/performance verifications are conducted in the ambient temperature, pressure, humidity, and cleanliness of the Space Station. If the station were to be operating in a degraded performance mode, then each calibration that was needed would be examined for validity under those conditions. If the conclusions is that the calibration would be invalid, then the unit would be replaced.

#### **4.2.3 Calibration Intervals**

On-orbit metrology intervals are expressed in days, months, or years. Some of the orbital equipment requires metrology/performance verification on a more frequent basis, between resupply flights, but these systems are designed to be self verifying or require the addition of a consumable standard fluid.

##### **4.2.3.1 Initial**

The initial calibration interval is based on the manufacturers sensor data, historical data for similar instruments, data developed during testing, and analyses which take into consideration the in-system application requirements for accuracy and confidence level. (See Appendix B-Metrology Process).

##### **4.2.3.2 Interval Adjustments**

Adjustments to the metrology interval are made based on the calibration history of the on-orbit sensors and any continued testing being conducted on the ground.

##### **4.2.3.3 Extensions**

Extensions to the metrology interval are made, by the SSCC or ESC, based on the manufacturer's proven recommendation, sensor calibration history, and performance history.

#### **4.2.4 Recall**

The mandatory recall of ORUs, containing sensors to be recalibrated, on or before the interval expiration date, is part of the logistic system. The replacement ORU is manifested for delivery to the Space Station on or before the scheduled replacement date. The replaced ORU is manifested for return subsequent to replacement and is scheduled for a metrology check, on the ground, prior to being refurbished or replaced.

#### **4.2.5    *Metrology Procedures***

The on-orbit metrology/performance verification procedures conducted, internal to the equipment or by the DMS, have been verified during the development and/or the qualification phases. The procedures for metrology/performance verification are referenced in TOMRS, for equipment requiring metrology/performance verification activity on-orbit.

#### **4.2.6    *Storage, Handling, And Transportation***

The storage, handling, and transportation of equipment on-orbit, is in accordance with the manufacturer's recommendations, and good practices. Equipment that is stored on-orbit that is intended to be used as a replacement for in-use equipment, is protected from conditions that would adversely affect the metrology of the equipment. The equipment is handled in a manner that neither damages the equipment nor adversely affects the calibration. The equipment is protected from damage while being transported from on-orbit storage to the intended installation location. The ability to protect calibrated items (including calibration standards) during transportation (launch loads) will be limited by the equipment design. This could preclude the use of many existing calibration standards regardless of how they are packaged, and require that special standards be developed.

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**APPENDIX A**  
**ABBREVIATIONS AND ACRONYMS**

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## ABBREVIATIONS AND ACRONYMS

ALAD	AIRESEARCH LOS ANGELES DIVISION
BIT	BUILT-IN-TEST
BML	BOEING METROLOGY LABORATORY
CDR	CRITICAL DESIGN REVIEW
DMS	DATA MANAGEMENT SYSTEM
DR	DATA REQUIREMENT
ECLSS	ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM
ESC	ENGINEERING SUPPORT CENTER
ETA	ENGINEERING TEST ARTICLE
FDI	FAULT DETECTION AND ISOLATION
GIDEP	GOVERNMENT-INDUSTRY DATA EXCHANGE PROGRAM
HML	HUNTSVILLE METROLOGY LABORATORY
IAV	INTERNAL AUDIO VIDEO
I/O	INPUT/OUTPUT
KSC	KENNEDY SPACE CENTER
LAB	LABORATORY
LFS	LORAL FAIRCHILD SYSTEMS
MSFC	MARSHALL SPACE FLIGHT CENTER
M&TE	MEASUREMENT AND TEST EQUIPMENT
MTBOOT	MEAN TIME BETWEEN OUT OF TOLERANCE
MTBF	MEAN TIME BETWEEN FAILURES
MTEMP	MEASUREMENT AND TEST EQUIPMENT METHODOLOGY PROGRAM

MTC	MAN-TENDED CAPABILITY
NASA	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
N <sub>2</sub>	NITROGEN
NIST	NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
NMI	NASA MANAGEMENT INSTRUCTION
OMI	ORBITAL MAINTENANCE ITEM
OOT	OUT OF TOLERANCE
ORU	ORBITAL REPLACEMENT UNIT
OSE	ORBITAL SUPPORT EQUIPMENT
PDR	PRELIMINARY DESIGN REVIEW
RID	REVIEW ITEM DISCREPANCY
SPC	STATISTICAL PROCESS CONTROL
SRD	SYSTEM REQUIREMENTS DOCUMENT
SSCC	SPACE STATION CONTROL CENTER
SSFP	SPACE STATION FREEDOM PROGRAM
SSMB	SPACE STATION MANNED BASE
TBE	TELEDYNE BROWN ENGINEERING
TCS	THERMAL CONTROL SYSTEM
TOMRS	TEST, OPERATIONS, AND MAINTENANCE REQUIREMENTS AND SPECIFICATIONS
UUT	UNIT UNDER TEST
WP01	WORK PACKAGE 01

**APPENDIX B**  
**METROLOGY PROCESS**

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## APPENDIX B – METROLOGY PROCESS

- B.1 Measurements Requirements
  - B.1.1 Definition Stages
  - B.1.2 WP01 Application
- B.2 Metrology Method
  - B.2.1 Requirements and Policy
    - B.2.1.1 SRD Requirements
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  - B.2.2 Steps of Method
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    - B.2.2.5 System Application Tolerance Requirements
    - B.2.2.6 Sensor Capabilities
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      - B.2.2.7.1 Allowable Sensor Tolerance
      - B.2.2.7.2 Drift Model Selection
        - B.2.2.7.2.1 Exponential Model
        - B.2.2.7.2.2 Other Models
    - B.2.2.8 ORU/OMI Reliability (MTBF)
    - B.2.2.9 Correction (Calibrate/Replacement) Interval
    - B.2.2.10 Calibration System Design
    - B.2.2.11 Measurement Traceability Requirement
  - B.2.3 Method Diagram

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## B.1 Measurements Requirements

The assurance of long term integrity of the WP01 Space Station Freedom systems is the underlying purpose of the metrology effort. This is to be accomplished by developing methods to determine when sensors are out of tolerance, predetermined responses when this occurs, and predictions of how often it should occur.

Sensor calibrations can be expected to drift. This drift can be characterized as an uncertainty associated with the measured value which grows with time. If undetected and uncorrected, it results in degraded system performance in the case of a control application, or in degraded data quality in the case of a scientific measurement. In either case a penalty is experienced in the form of wasted resources, shorter component life, inconclusive data, or any number of other factors which were considerations in setting the system operational tolerance parameters. A system which operates outside of its specified range is costing something if the right requirements were set at the start.

Knowing that a sensor is operating within tolerance is a matter of degree. There is some uncertainty that a sensor that has recently been calibrated, and is being cross-checked by several other sensors of dissimilar construction, is in fact in-tolerance. In this case, the uncertainty is small. A sensor that has recently been calibrated and which is being cross-checked by an identically constructed unit has a greater uncertainty in its measurement due to the numbers of sensors involved, and the fact that identical units may tend to drift alike in response to the same environment. A sensor which is not being cross-checked with other sensors would have an even greater associated uncertainty. If the factor of extended time since calibration is added to these scenarios, an increased uncertainty will be added to each.

Figure B-1 shows the options for reducing the uncertainty if calibration using a recognized standard is not possible. The center column starts with a self calibrating sensor. This approach results in the smallest uncertainty. Next in the column is the use of many dissimilar sensors to verify the performance of the prime unit. This is a low risk approach also, but not as good as self calibrating, because the individual units will each drift with time and eventually deliver a scattering of answers. Next in the column is the redundant identical sensor approach. This is much better than having no verification, but allows for a greater uncertainty than many dissimilar units. Finally, the case of having no verification of a sensor performance is encountered. In this instance, the system level Fault Detection and Isolation procedure will find the faulty sensor when the performance becomes so bad that the system performance tolerance limit is reached if the sensor is used in a control function. This allows the system to operate for some extended period of time near the limit of degraded performance. An alternative to achieving the uncertainty levels of the verified sensor cases would be the periodic change out of sensors. Longer periods of service would result in greater uncertainties. This forces the system to operate for some extended period in a degraded performance mode. The penalty here is the spares provisioning and extra crew time needed to perform the replacements. A third option, and one that offers great promise where applicable, is the employment of an analytical technique known as Process Fault Diagnosis. This technique uses knowledge of the system nominal operating conditions to identify parameter changes and associates the changes with sensor errors. This approach requires additional diagnostic computations, but does not generally depend on redundant sensors.

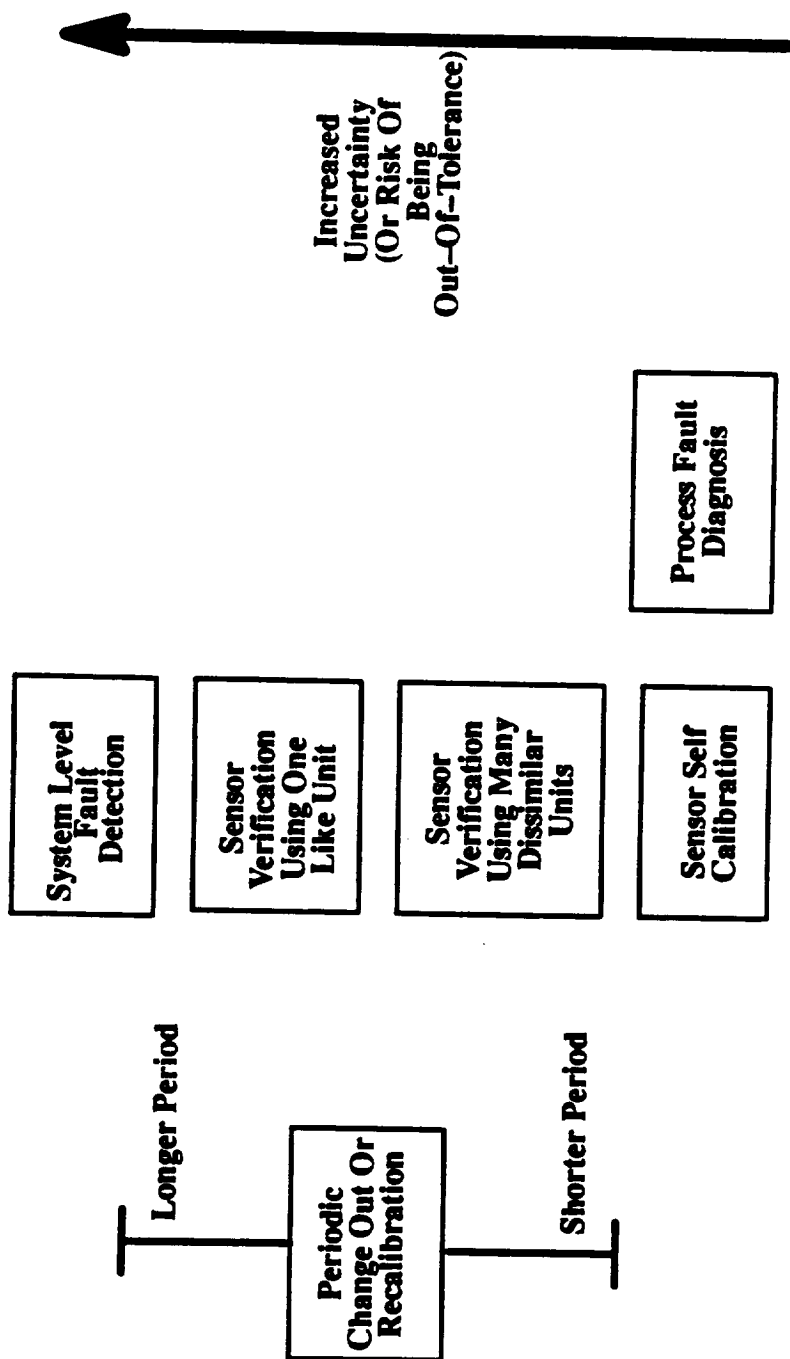


FIGURE B-1 OPTIONS FOR REDUCING MEASUREMENT UNCERTAINTY

Decreasing the uncertainty often has an associated cost of adding more sensors, more data processing, more spares/crew time, or developing a more complex self-calibrating unit.

Having determined that a sensor is out-of-tolerance, the questions remain of how should we respond, and how often should this occur? The possible responses include recalibration/adjustment of the unit or associated coefficients, replacement of the unit, or discontinuing the use of data from the unit.

The following sections will discuss the sequence of defining the measurements requirements, relate this sequence to the current WP01 Space Station Freedom Program sequence, and define the method to be followed in implementing these principles.

### B.1.1 Definition Stages

Every design must begin with requirements. The NASA Metrology, Calibration, and Measurement Process Guidelines, (NHB 5330.9 (1A)), working copy dated January 7, 1992, contains a ten stage sequence that describes the actions that should be taken to develop requirements for measuring systems. These requirements are to ensure the development of measurement systems that provide the necessary confidence levels for decisions that are to be made, or data that are to be collected.

This sequence is summarized as follows:

Stage 1 – Mission Profile: Define the objectives of the mission and what confidence levels are required from the measurements.

Stage 2 – Measurement System Performance Profile: Define the required mission measurement capability.

Stage 3 – Measurement System Performance Attributes: Define the required system measurement capability.

Stage 4 – Measurement Component Performance Attributes: Define the required component measurement capability.

Stage 5 – Measurement Parameters: Define measurable characteristics that accomplish the component measurement capability.

Stage 6 – Measurement Process Requirements: Define the parameter values, reliability values, and measurement confidence levels.

Stage 7 – Measurement System Design: Design measurement techniques.

Stage 8 – Calibration Process Requirements: Define the calibration parameters and intervals.

Stage 9 – Calibration System Design: Design the calibration system.

Stage 10 – Define the traceability from the unit under test to the Standards Laboratory.

### B.1.2 WP01 Application

This sequence of stages is the ideal process to follow given sufficient time, resources, and a stable set of system top level requirements. In the case of the redefined and restructured Space Station Freedom baseline, this sequence has not been rigorously followed. The sequence has generally been followed in Stages 1 through 5, but Stage 6 was only partially completed before Stage 7 was implemented. Stages 8 through 10 are yet to be implemented.



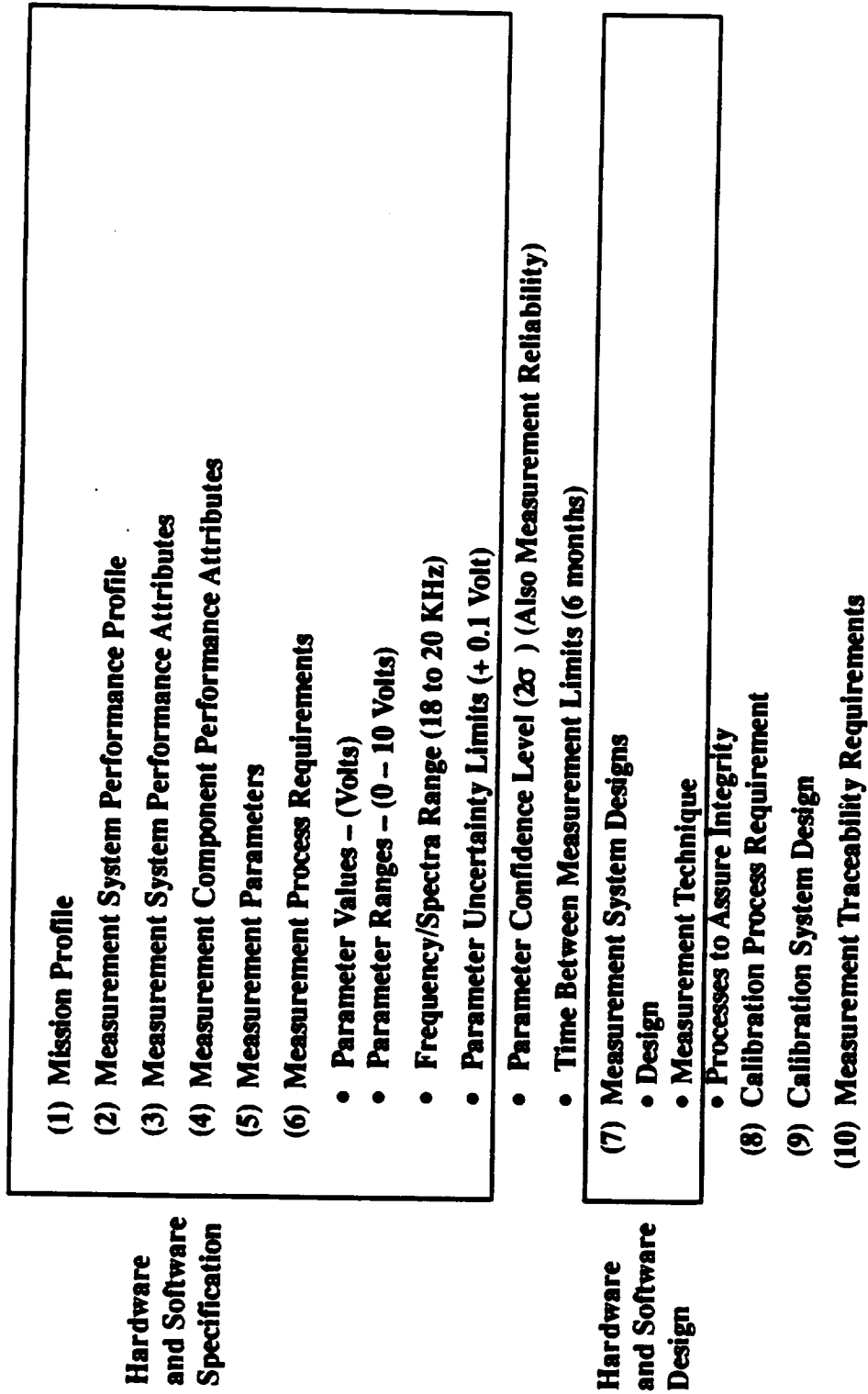


FIGURE B-2 STAGES OF MEASUREMENT REQUIREMENTS DEFINITION

Figure B-2, Stages of Measurement Requirements Definition, illustrates the implementation so far. Stages 1 through 5 were generally implemented in the Hardware and Software Specifications.

Some of the requirements in Stage 6 were also implemented in the Hardware and Software specifications and the preliminary Hardware and Software designs. Others, chiefly parameter confidence levels and time between measurements limit, have been ignored.

Stage 7 was partially implemented in the Hardware and Software preliminary designs. The portion of Stage 7 that pertains to measurement techniques and processes to assure data integrity is incomplete. This involves defining the need to verify sensor performance, and the method to accomplish the verification.

The Calibration Process, Calibration System Design, and Measurement Traceability Stages 8, 9, and 10 can proceed only after the units to be calibrated on orbit have been identified.

These are the conditions as they exist. What is needed now is an interpretation of this partially implemented sequence into a method for accomplishing the required long-term integrity. The sections that follow address this method.

## B.2 Metrology Method

A method to accomplish the goals of the measurements requirements definition sequence of stages has been developed to use the existing design data and measurements approaches as a starting point, and to conclude with the required long-term system integrity.

The method can be defined by the following steps:

- A. Define Sensor/Application criticality.
- B. Define Out-of-tolerance (OOT) detection and isolation process and procedure.
- C. Determine if unit correction (calibration/replacement) is to be scheduled or conditional.
- D. Determine if the out-of-tolerance unit is to be calibrated or replaced. (Perform a trade study.)
- E. Define system application tolerance requirements.
- F. Survey sensors and define capabilities.
- G. Define expected in-tolerance period for sensors in applications.
- H. Define the sensor ORU/OMI expected reliability. (MTBF)
- I. Define correction (calibrate/replacement).
- J. Calibration system definition and design.
- K. Measurement Traceability requirements.

These steps will be examined in detail following a brief review of the requirements and policy that underlay the process.

## B.2.1 Requirements and Policy

The Space Station Freedom Program Level III System Requirements Document (SS-SRD-0001E, Sec. 3, June 23, 1992) has a number of requirements which impact the metrology process.

These requirements have been interpreted and defined in more detail as a working document in the Boeing Fault Detection and Isolation and Built-In-Test Approach/Policy. This Policy has been used as a point of departure for the metrology process requirements definition.

### B.2.1.1 SRD Requirements

Some selected requirements which have been used to guide the development of the policy are listed, and their original paragraph numbering has been retained to facilitate traceability.

#### FLIGHT SYSTEM FAULT DETECTION AND ISOLATION (3.1.9.2.1)

All WP01 flight systems including those supporting Category 3 functions, shall make operational and fault detection and isolation (FDI) data available to the SSFP data management function for transmission to the ground. (3.1.9.2.1.1)

WP01 systems which support category 1, 1C, 2, and 2S functions shall meet the following FDI requirements on-board: (3.1.9.2.1.2)

Failure of a redundant string shall be automatically detected. (3.1.9.2.1.2.1)

Failure data shall be automatically provided to the SSFP data management function for notification to the crew, when applicable, and ground. (3.1.9.2.1.2.2)

Failures shall be isolated to the level necessary for reconfiguration. (3.1.9.2.1.2.3)

Systems shall interrogate ORU operational parameters and/ or BIT circuits on a scheduled basis and on demand. (3.1.9.2.1.2.4)

System and ORU designs shall provide the capability (via status data, test points, or other means) for monitoring, checkout, fault detection, and isolation to the on-orbit repairable level without requiring removal of ORUs. (3.1.9.2.1.4)

Automated FDI shall not be required for the following types of crew interface equipment; visual displays, keyboards, lights, and speakers. (3.1.9.2.1.5)

Ground-based diagnostic software and human analysis (ground FDI) shall provide the processing capability to detect any functional failures not detected on board. (3.1.9.2.2.1)

Ground FDI shall provide the processing capability to isolate faults affecting category 1, 1C, 2, and 2S functions to a single ORU. (3.1.9.2.2.2)

#### FUNCTION CATEGORIZATION (3.1.10.1.1.6)

Table B-1 specifies SSMB function categorization and failure tolerance requirements..

Systems/equipment that support Category 1, 1C, and 2S functions shall be designed such that no single data instrumentation failure causes loss of a functionally redundant path. (3.1.10.2.2.3)

TABLE B-1 SSMB FUNCTION CATEGORIZATION AND FAILURE TOLERANCE

FUNCTION CATEGORIZATION		FAILURE TOLERANCE REQUIREMENTS		
FUNCTION CATEGORY	PURPOSE OF FUNCTION	FUNCTIONAL FAILURE TOLERANCE	STATUS AFTER FAILURE	
			FAILURE 1	FAILURE 2
1	SSMB Survival	1 Failure Tolerant 5,6	Operational (within performance specification)	
1C	Crew Survival	2 Failure Tolerant 4	Operational (within performance specification)	Operational 2 (degraded performance permitted)
2	Mission Success	1 Failure Tolerant 5	Operational (degraded performance permitted)	
2S	Safety Monitoring and Emergency Control	1 Failure Tolerant 5	Operational (within performance specification)	
3	Support for Individual Payload Operations & all other Functions	0 Failure Tolerant		

- 1 Failure tolerances shall be determined based upon the worst case.
- 2 Degraded performance may be permitted for certain functions if the SSMB can be configured in a safe operational mode and failure tolerance can be restored.
- 3 All failures shall fail in a safe mode.
- 4 1 Failure Tolerant allowed during periods of maintenance.
- 5 0 failure Tolerant allowed during periods of maintenance.
- 6 Those Category 1 functions that are shown to be time critical may be required to be 2 failure tolerant.

Systems/equipment that support Category 1, 1C, and 2S functions shall be designed such that no single control instrumentation failure causes loss of more than one functionally redundant path. (3.1.10.2.2.4)

#### B.2.1.2 FDI and BIT Policy

The germane metrology requirements have been extracted and are listed here for quick reference. Again, the original paragraph numbering has been preserved for ease of traceability.

### FAULT DETECTION ISOLATION (3.2.4.3)

#### Definitions (3.2.4.3.1)

**Built-In-Test (BIT)** – An integral capability of the mission equipment which provides an on-board automated test capability to detect, diagnose, and/or isolate failures.

**Detection** – Discovery of the existence of a fault.

**Diagnostic Software** – Application software that performs analysis of operational parameters, status information, and fault detection/isolation information to ensure the equipment is functioning within its specified functional performance limits.

**Fault** – A fault is a degradation to a condition outside of specified functional performance limits.

**Fault Isolation Test (FIT)** – A test that isolates a detected fault to the ORU.

**Isolation** – The process of identifying and locating a fault to a single ORU.

**ORU Status.** Indication of whether the ORU is fully operational, partially operational, or inoperative.

#### ORU With Embedded Processing Capabilities (3.2.4.3.3)

##### CATEGORY 1, 2, and 2S ORUs (3.2.4.3.3.1) (ORUs supporting category 1, 2, 2s functions)

**Built-In-Test (BIT)** functions shall detect at least 96 percent of the ORU's faults. Passive mode BIT shall be capable of detecting at least 90 percent of the ORU's faults. Active mode BIT shall augment passive BIT as required to ensure that BIT is capable of detecting at least 96 percent of the ORU's faults. (a)

Self-test provisions shall be incorporated into the ORU as a means of insuring unambiguous BIT readouts. (b)

The ORU shall store all fault detection and isolation information used in failure diagnostics until such information is transmitted to the diagnostic software. (i)

The BIT shall report the ORUs status to the diagnostic software. (p)

##### Category 3 ORUs (3.2.4.3.3.2) (ORUs supporting category 3 Functions only)

Self-test provisions shall be incorporated into the ORU as a means of insuring unambiguous BIT readouts. (a)

**Built-In-Test (BIT)** functions shall detect at least 96 percent of the ORUs faults. (c)

The BIT shall report the ORU's status to the diagnostic software. (g)

#### ORU Without Embedded Processing Capabilities (3.2.4.3.4)

Sensors or other devices shall be provided which monitor and report ORU operational parameters to the diagnostic software. (a)

Sensors or other devices shall provide the capability to detect at least 96 percent of the ORU's faults. (b)

Sensor or other device faults shall be detectable. (c)

Flight Level Diagnostic Software Requirements (3.2.4.3.5)

Category 1 2, and 2S Requirements (3.2.4.3.5.1)

The diagnostic software shall receive fault detection information or operational parameters from the ORUs. (a)

The diagnostic software in conjunction with BIT shall detect 100 percent of ORU faults. (b)

Fault detection and isolation information shall be time tagged and stored until such information is downlinked. (h)

During normal operations the diagnostic software shall interrogate the BIT of embedded processor based ORUs or interrogate the operational parameters of non-embedded processor ORUs every sixty (60) seconds. (j)

Category 3 Requirements (3.2.4.3.5.2)

The diagnostic software shall receive fault detection information or operational parameters from the ORUs. (a)

Fault detection information shall be time tagged and stored until such information is downlinked. (b)

Ground Level Diagnostic Software Requirements (3.2.4.3.6)

The ground shall receive ORU status and diagnostic software information. (a)

For category 3 functions, crew interface, and diagnostic software in conjunction with downlink of ORU status and flight diagnostic software data shall detect 100 percent of ORU faults. (b)

For all Category 1, 2, and 2S functions, the diagnostic software in conjunction with downlink of ORU status and flight diagnostic software data shall isolate 90 percent of faults to a single ORU. For all functions, manual methods shall augment diagnostic software to isolate 100 percent of faults to a single ORU. (c)

**B.2.1.3 Rationale and Conclusion**

A look at the ground level diagnostic software paragraphs (3.2.4.3.6 b,c) will reveal that 100 percent of ORU faults must be detected. A fault is described in the definitions as operation outside of functional performance limits. A tree to sort out the point at which out-of-tolerance Fault Detection is performed for each type of ORU (Embedded Processor or not), and each category of ORU, is developed in Section B.2.2.2, Out-Of-Tolerance Procedure. This tree is based on the policy items shown in Section B.2.1.2, FDI and BIT Policy.

**B.2.2 Steps of Method**

These steps have been ordered as shown to drive out as early as possible any new requirements for additional sensors, system reconfiguration, analysis capability, or calibration equipment. It is also desirable to learn about impact to spares provisioning and crew time as the measurement specifics can be developed. These relationships are illustrated in Figure B-3, Metrology Method Steps. These steps will be discussed in detail in the following sections.

STEPS		IMPACTS
1	<ul style="list-style-type: none"><li>• ORU Functional Category</li><li>• Out-Of-Tolerance Procedure</li><li>• Scheduled or Conditional</li><li>• Calibrate or Replace</li></ul>	• Additional Sensors
2		• System Reconfiguration
3		• Additional Analyses Capability
4		• Calibration Equipment
5	<ul style="list-style-type: none"><li>• System Application Tolerance Requirements</li><li>• Sensor Capabilities</li><li>• Sensor Drift Interval</li><li>• ORU/OMI Reliability</li><li>• Correction (Calibrate/Replacement) Interval</li></ul>	• Spares Provisioning
6		• Crew Time Requirements
7		
8		
9	<ul style="list-style-type: none"><li>• Calibration System Design</li><li>• Measurement Traceability Requirement</li></ul>	• Storage Requirements
10		• Crew Training
11		• Resupply Requirements

FIGURE B-3 METROLOGY METHOD STEPS

#### B.2.2.1 ORU Functional Category (Step 1)

The correct classification of the mission criticality of a sensor which is an ORU/OMI, or is embedded in an ORU/OMI, is pivotal because it influences a number of subsequent steps and choices or decisions in the metrology method. The sensor category can be determined for the instance specific application of each ORU by looking in the hardware B1 Specification. Also, the most critical sensors should receive the first priority in being processed through the metrology method.

#### B.2.2.2 Out-Of-Tolerance Procedure (Step 2)

A decision matrix to determine if each ORU that has embedded sensors satisfied the policy requirements has been developed based on discussions contained in Section B.2.1, Requirements and Policy. This method is presented in Figure B-4, Sensor Tolerance Maintenance Decision Matrix. The flowchart is entered at the top where the word "start" appears. The first decision (1) involves excluding discrete sensors, those that do not provide proportional outputs (digital or analog) from the group that requires calibration. If they were not calibrated originally, then they will not require it on orbit.

The next decision (2) determines if the ORU has an embedded processor, because the requirements are different depending on the answer. Decisions (3) finds out if BIT will detect an out-of-tolerance fault. If not, decision (4) places the ORU by Category as defined in Table B-1, Section B.2.1.1. Categories 1, 2, and 2S are tested for detectability in decision (5). Category 3 is tested for detectability in decision (6). ORUs without embedded processors are separated according to category at decision (7). Categories 1, 2, and 2S are tested for detectability at decision (8) and Category 3 is tested for detectability at decision (9). There are two types of results. The ORU is determined to meet requirements and reaches a decision end entitled "Design OK" or the ORU is determined to not meet requirements and reaches a decision end entitled "Mandatory Design Change". Each ORU containing sensors will be subjected to this decision matrix, and the decision box reached, labeled with a number and a letter, will be recorded. For those with "Design OK" conclusions, a rationale sheet will be prepared describing how the fault is detected. This may involve cross checking between sensors, operating at a set point to check parameter values, or Process Fault diagnosis based on process model knowledge. The requirements allow any and all of these approaches to out-of-tolerance fault detection. For those with a "Mandatory Design Change" conclusion, a design change will be implemented to correct the problem, and then the decision matrix will be entered again to define compliance. The purpose of this matrix is to ensure that in each instance the designers have recognized the requirement to detect a fault, and that an out-of-tolerance sensor comprises a fault. Once this recognition has occurred and the fault has been identified, the detection and isolation process can be treated as any other fault by the designers, the reliability analysts, the maintainability analysts, the operations analysts, the logisticians, and any other impacted functional groups.

#### B.2.2.3 Scheduled or Conditional (Step 3)

The Preventative Maintenance analysis methodology contained in the WP01 Maintainability Allocation, Predictions And Analyses Report, Issue D, (D683-10483-1) Section 2.6 has been employed to determine those ORUs which should be replaced on a schedule rather than waiting for a failure to occur (conditional). The results of the preliminary analysis are contained in that document's Appendix G, Preventative Maintenance Assessment.



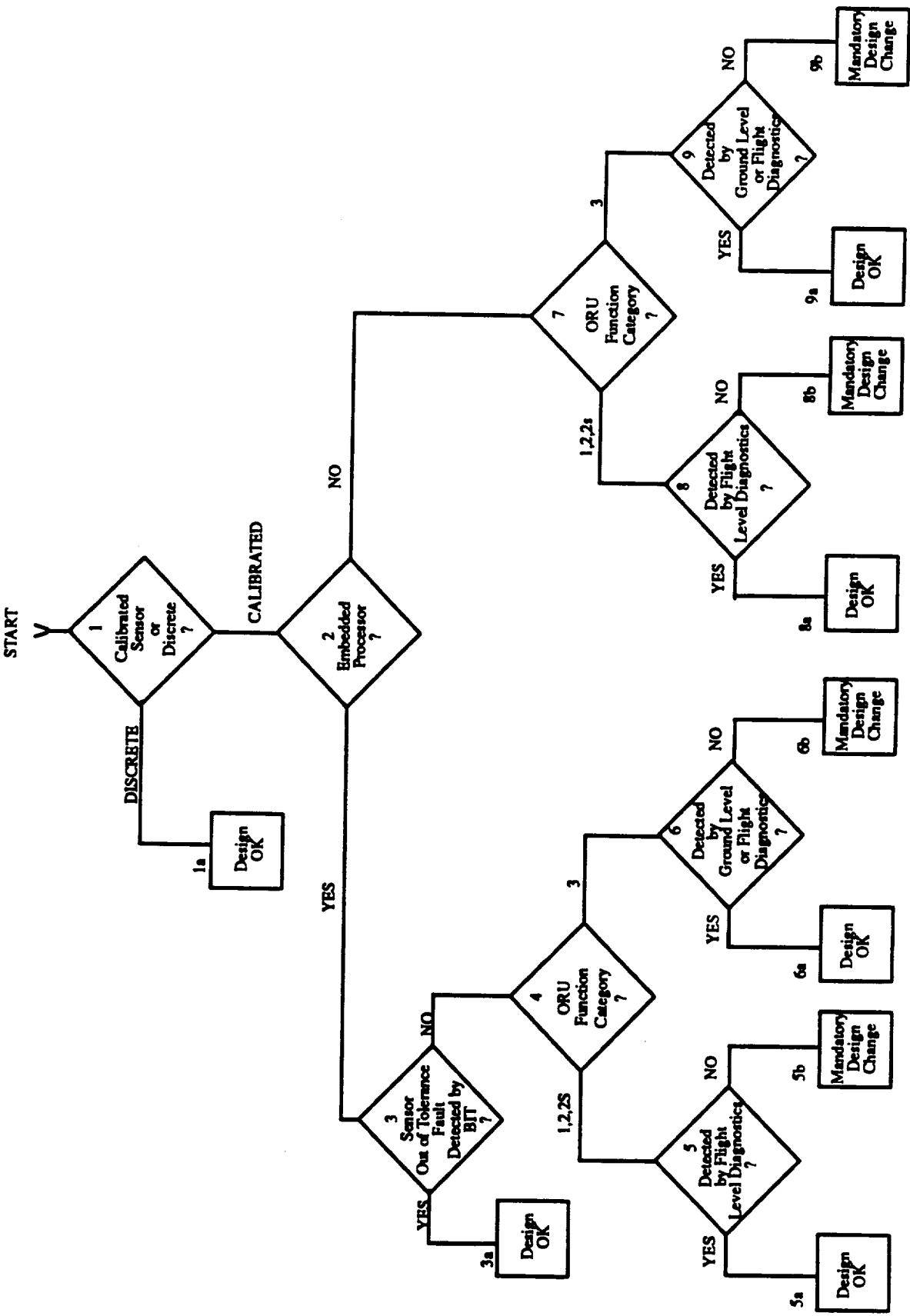


FIGURE B-4 SENSOR TOLERANCE MAINTENANCE DECISION MATRIX

**B.2.2.4 Calibrate or Replace (Step 4)**

The decision to calibrate or replace an ORU when a sensor goes out-of-tolerance (experiences a fault) will be based on a trade off. This trade off must examine the impacts of making the correction each way. For an ORU that is calibrated, the impacts include calibration equipment, crew training and crew time to perform. For an ORU that is replaced, the impacts include spares crew training and crew time. This trade off should include members from all impacted disciplines and will include as a minimum: Engineering, Logistics, Reliability, Maintainability, and Operations. The trade off rationale, analysis, and conclusions will be documented in the appendix of this plan.

**B.2.2.5 System Application Tolerance Requirements (Step 5)**

A key piece of information that is necessary to performing an assessment of the sensor expected period of operation within tolerance is the system application tolerance requirement. Sensors may be purchased and accepted with a tolerance which is much tighter than that which is required by the system in which it is used. Sometimes this is done to allow the sensor to drift for a long time before it reaches an out-of-tolerance condition for the system. The system application tolerance requirements must be established for each instance where a sensor is used.

**B.2.2.6 Sensor Capabilities (Step 6)**

The basic characteristics of a sensor must be established to facilitate the analyses to determine the expected in-tolerance period and to predict whether the sensor should be expected to stay in tolerance to the point where the ORU is replaced due to another failure mode occurring.

The prime sensor data required are parameter range (0-10 volts), parameter uncertainty limits (+/-0.1 volt), parameter confidence level ( $2\sigma$ ). The additional required sensor characteristics of mean-time-between-out-of-tolerance (MTBOOT) and mean-time-between-failures (MTBF) will be addressed in Sections B.2.2.7 and B.2.2.8 respectively. Other useful sensor characteristics such as input power, output, weight, size, and operating environment capability will be collected along with the prime parameters.

During sensor selection, a number of characteristics are considered which are not necessary for the metrology process. A list of typical sensor characteristics are shown in Table B-2, sensor selection criteria.

**B.2.2.7 Sensor Drift Interval (Step 7)**

To determine the sensor drift interval in the application we must first establish the allowable sensor tolerance limits. This application or allowable sensor tolerance is determined by well-established techniques that are covered extensively in the Metrology, Calibration, and Measurement Process Guidelines (NHB 5330.9 (1A)). The technique is summarized here and then the calculation for drift interval ( $t$ ) is developed.

**B.2.2.7.1 Allowable Sensor Tolerance**

To determine the allowable application tolerance for the sensor, an error budget must be established through an uncertainty analysis. To accomplish this, the first step is to study the measurement system and data algorithm to determine the error sources which must be considered. When the list is complete, an uncertainty estimate must be assigned to each error source except for the sensor which will be calculated as the end result of this procedure. Each error source will then be classified as being a bias type (drift) or a precision type (MDM digitizing increment). The total bias errors ( $B_t$ ) can be combined using the RSS method:

TABLE B-2 SENSOR SELECTION CRITERIA

- |   |                           |
|---|---------------------------|
| • RANGE                                 | • WEIGHT                  |
| • UNCERTAINTY LIMITS                    | • VOLUME                  |
| • OUTPUT FORM                           | • TESTABILITY             |
| • POWER IN                              | • CALIBRATION EQUIPMENT   |
| • STABILITY/HISTORICAL DATA<br>(MTBOOT) | • COOLING/OTHER RESOURCES |
| • RELIABILITY (MTBF)                    | • NONINTRUSIVE            |
| • MAINTAINABILITY (MTTR)                | • ADJUSTABLE              |
| • RESPONSE TIME                         | • AVAILABILITY            |
| • LINEARITY                             | • COST                    |
| • ENVIRONMENTAL/ACCELERATION            | • COMMONALITY/DIVERSITY   |

$$B_T = \sqrt{b_1^2 + b_2^2 + \dots + b_n^2}$$

In this equation,  $b_1$ , will represent the allowable sensor bias (drift) error. The total precision errors ( $S_T$ ) can be combined likewise:

$$S_T = \sqrt{s_1^2 + s_2^2 + \dots + s_n^2}$$

The total bias and precision errors ( $U_{RSS}$ ) may be combined using the RSS method:

$$U_{RSS} = \sqrt{(B_T)^2 + (2S_T)^2}$$

$$U_{RSS} = \sqrt{\left( \sqrt{b_1^2 + b_2^2 + \dots + b_n^2} \right)^2 + \left( 2\sqrt{s_1^2 + s_2^2 + \dots + s_n^2} \right)^2}$$

System Requirement      Sensor Allowable Tolerance      other bias errors      Precision errors

If we combine the known error sources in the following fashion, they can be reduced to constants to simplify the remaining procedure.

Then

$$c_1 = b_2^2 + \dots + b_n^2 \quad (b_1 \text{ is not included})$$

$$c_2 = s_1^2 + s_2^2 + \dots + s_n^2$$

$$U_{RSS} = \sqrt{(\sqrt{b_1^2 + c_1})^2 + (2\sqrt{c_2})^2}$$

Solving for  $b_1$ ,

$$U_{RSS}^2 = (\sqrt{b_1^2 + c_1})^2 + (2\sqrt{c_2})^2$$

$$U_{RSS}^2 = b_1^2 + c_1 + 4c_2$$

$$b_1^2 = U_{RSS}^2 - c_1 - 4c_2$$

$$b_1 = \sqrt{U_{RSS}^2 - c_1 - 4c_2}$$

This yields the allowable sensor error tolerance in the system application.

#### B.2.2.7.2 Drift Model Selection

A number of models are discussed in NHB 5330.0(1A) but only one of them, the exponential model, is developed and expanded through the case studies. The exponential model may be appropriate in some cases, and inappropriate in others. Our approach will be to characterize the mechanisms responsible for sensor drift for each type of sensor, and accumulate any historical data available before selecting a drift model in each case.

##### B.2.2.7.2.1 Exponential Model

The exponential model is an appropriate model of time to effect for failure mechanisms resulting from Poisson (random) processes. One of the key features of the exponential model is that it

has no memory; i.e., the future performance of an item is not dependent upon its past performance. This type of model is not considered appropriate for mechanisms such as accumulated damage or wear in which future performance is dependent upon component history.

#### A. Finding MTBOOT

MTBOOT can be determined in a number of ways that include using historical calibration data, accelerated life testing results, component analysis mixed with engineering judgement, and manufacturers specifications. The most commonly understood method is to use historical calibration data. This approach employs the reliability equation, where sensor uncertainty with time has been characterized by an exponential model,

$$R_{\text{eop}} = R_{\text{bop}} e^{-\frac{t}{\text{MTBOOT}}}$$

Where  $R_{\text{eop}}$  = Reliability (percent in tolerance) at the end of period

$R_{\text{bop}}$  = Reliability (percent in tolerance) at the beginning of period

$t$  = Usage time on the unit (sensor)

MTBOOT = Mean-time-between-out-of-tolerance

Given the usage time ( $t$ ), the reliability at the beginning of the period ( $R_{\text{bop}}$ ), and the reliability at the end of the period ( $R_{\text{eop}}$ ), the MTBOOT is determined.

Solving for MTBOOT yields

$$\text{MTBOOT} = -\frac{t}{\ln\left(\frac{R_{\text{eop}}}{R_{\text{bop}}}\right)}$$

If historical data are not available, then special testing may be necessary to arrive at an MTBOOT with a high confidence level. This may be necessary for items of the greatest criticality. Others may be defined satisfactorily using component modeling mixed with engineering judgement, or manufacturers specifications. When a manufacturer quotes an MTBOOT, the question must be asked, "How does the supplier know?" The answer will determine the confidence in the manufacturers data.

#### B. Sensor drift model

To model sensor drift, we use the reliability equation,

$$R_{\text{eop}} = R_{\text{bop}} e^{-\frac{t}{\text{MTBOOT}}}$$

We are generally supplied with a sensor of known characteristics at the beginning of the period. The problem is to predict at what point in the future will the drift reach a point where

the sensor measurement reliability has become unacceptable for the defined application system tolerance.

The situation is illustrated in Figure B-5, Sensor Measurement Uncertainty Growth. Reliability is defined as the area (percent) under the normal curve that is between the tolerance limits. In this illustration the tolerance limits would be the acceptance limits on a new sensor. The reliability at usage time  $t$  would be for the original sensor limits. The desire is to know the reliability using the system application limits, or conversely, to find the usage time at which the system application limits would be reached. This can be achieved as follows;

Given  $R_{bop}$  = Original Sensor reliability (100%)

$V_1$  = Sensor tolerance limits (acceptance value)

$V_2$  = Allowable sensor tolerance limits (in system application)

$R_D$  = Desired system measurement reliability (assumed)

MTBOOT = Mean-time-between-out-of-tolerance for original sensor limits ( $V_1$ )

The desired system reliability ( $R_D$ ) is illustrated in Figure B-6.

Probability tables based on the normal distribution list area under the curve from  $-\infty$  to  $Z$ . Figure B-7 illustrates this relationship.

The probability associated with the area between  $+Z$  and  $-Z$ , corresponds to the allowable sensor application tolerance limits. Figure B-8, Allowable Sensor Application Tolerance Limits, shows the relationships.

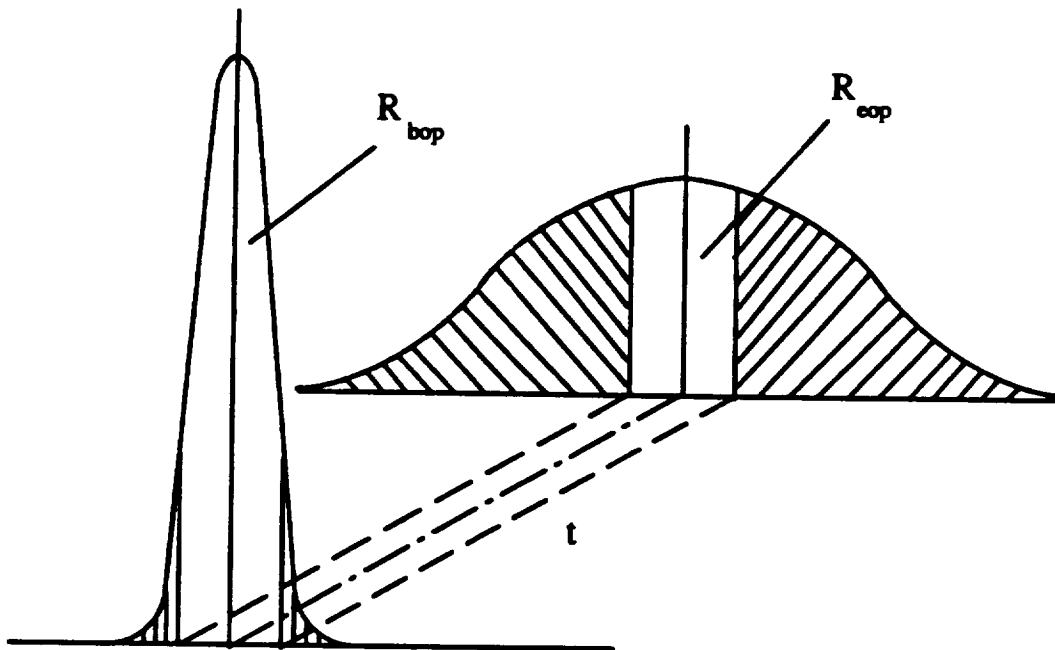


FIGURE B-5 SENSOR MEASUREMENT UNCERTAINTY GROWTH

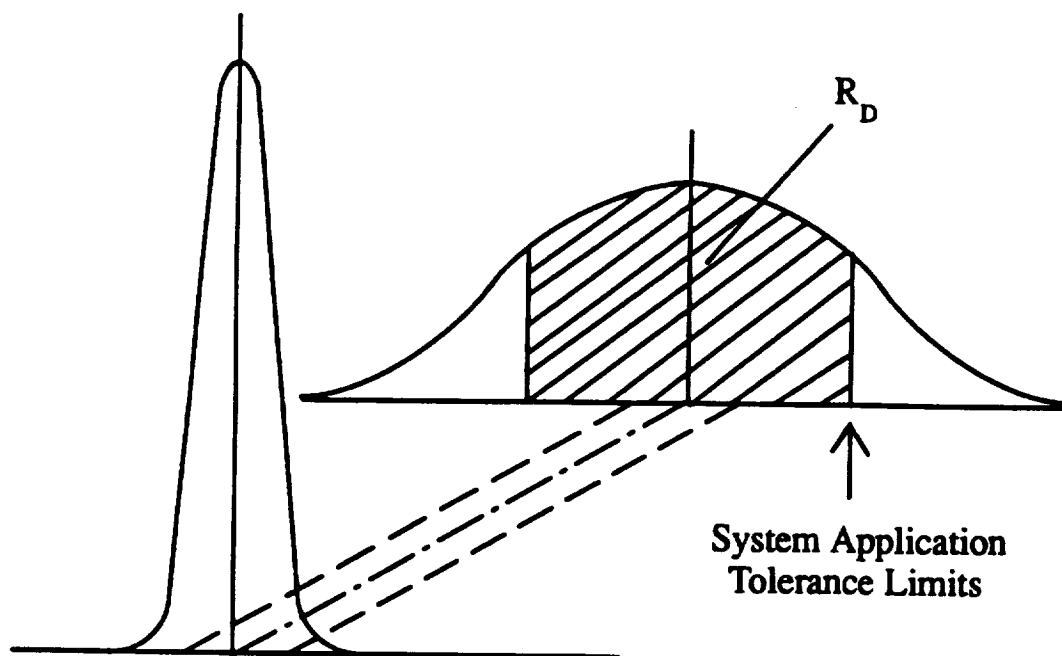


FIGURE B-6 DESIRED SYSTEM RELIABILITY

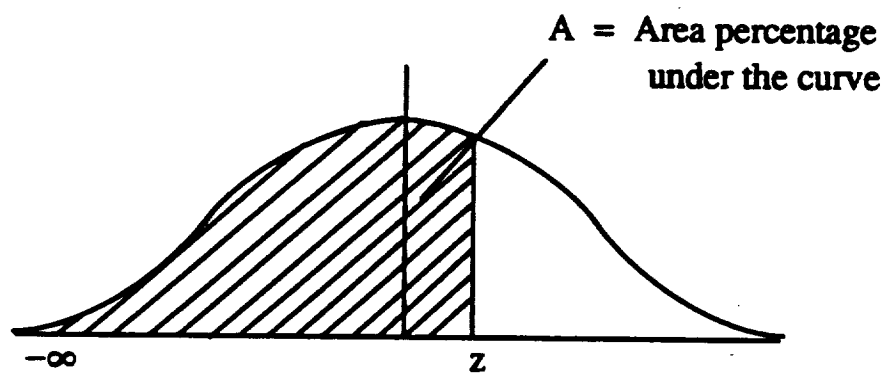


FIGURE B-7 PROBABILITY TABLE PARAMETERS



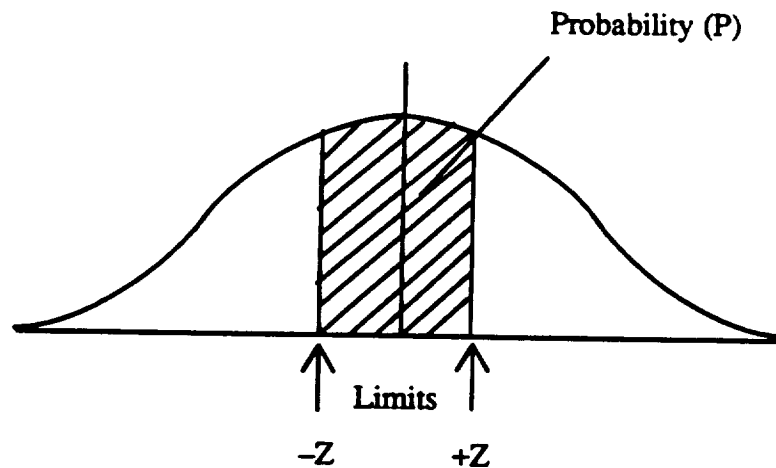


FIGURE B-8 SYSTEM APPLICATION TOLERANCE LIMITS

Given the desired probability ( $R_D$ ) we can use the expression

$$A_2 = \frac{R_D}{2} + 0.5$$

to determine the area in the tables corresponding to this probability. This area ( $A_2$ ) can be used to look up the  $Z_2$  value, where  $Z$  is the abscissa value that results in a probability of  $R_D$ .

Then we can relate the tolerance limits to the  $Z$  values by

$$\frac{V_1}{Z_1} = \frac{V_2}{Z_2}$$

We were given  $V_1$  and  $V_2$ . We deduced  $Z_2$  from  $R_D$  by using the tables, so we can solve for  $Z_1$ .

$$Z_1 = \frac{V_1 Z_2}{V_2}$$

This is used in the tables to find the area  $A_1$  which corresponds to the reliability measured against the acceptance limit  $V_1$  at the end of the period  $Reop$ :

$$R_{\text{oop}} = 2(A_1 - 0.5)$$

Rearranging the reliability equation we have,

$$t = -\text{MTBOOT} \ln \left( \frac{R_{\text{oop}}}{R_{\text{bop}}} \right)$$

We substitute the known values to find  $t$ , the usage time at which the sensor drift error should reach the system tolerance limit. (Sensor Drift Interval)

This procedure will be installed in a computer code to make it easy to apply and to ensure uniform results.

#### B.2.2.7.2.2 Other Models

Other reliability models are available to describe time-dependent failure mechanisms. However, on the SSF project, wearout mechanisms are characterized by a "life" parameter. There are a number of reasons for this approach, the most important of which is that data of sufficient fidelity to properly characterize more sophisticated reliability models (e.g., 3-parameter Weibull) are simply not widely available. A single parameter model, component life, is more defensible, technically, than a more complicated, multi-parameter model, especially when the parameter(s) must be based on engineering judgement.

#### B.2.2.8 ORU/OMI Reliability (MTBF) (Step 8)

The reliability, or mean-time-between-failures (MTBF) of the ORU/OMI that contains the sensor is required for the next step in this procedure. It is typically determined by the Reliability group. In addition, the ORU/OMI is sometimes specified to have MTBF and life limit targets.

#### B.2.2.9 Correction (Calibrate/replacement) Interval (Step 9)

The expected or planned correction interval, depending on the choice of scheduled or conditional correction, will be determined by the Reliability group from consideration of the ORU/OMI MTBF and the drift intervals of its contained sensors.

#### B.2.2.10 Calibration System Design (Step 10)

If the choice in Section B.2.2.4 was to calibrate, and the procedure described in Section B.2.2.6 has been used to determine the calibration requirements, then design of the calibration system may begin. Factors to consider in design of a calibration system are listed in Table B-3, Calibration System Design Criteria.

**TABLE B-3 CALIBRATION SYSTEM DESIGN CRITERIA**

- **PARAMETER RANGE**
- **SIZE**
- **WEIGHT**
- **STABILITY**
- **ACCURACY**
- **TRAINING REQUIREMENT**
- **FREQUENCY OF CALIBRATIONS**
- **TIME TO CALIBRATE**
- **POWER**
- **TRACEABILITY**
- **ENVIRONMENTAL EFFECTS**

**B.2.2.11 Measurement Traceability Requirement (Step 11)**

Traceability is a hierarchical process. Calibrations must be traceable to NIST (formerly the National Bureau of Standards) to be considered valid. Maintenance of this chain from the Unit Under Test (UUT) all the way up to the national Standards Laboratory is the defining characteristic of traceability. The quality of the decision based on the measurement is dependent on the quality of the traceability path. The result of this step is a traceability diagram for the calibration equipment.

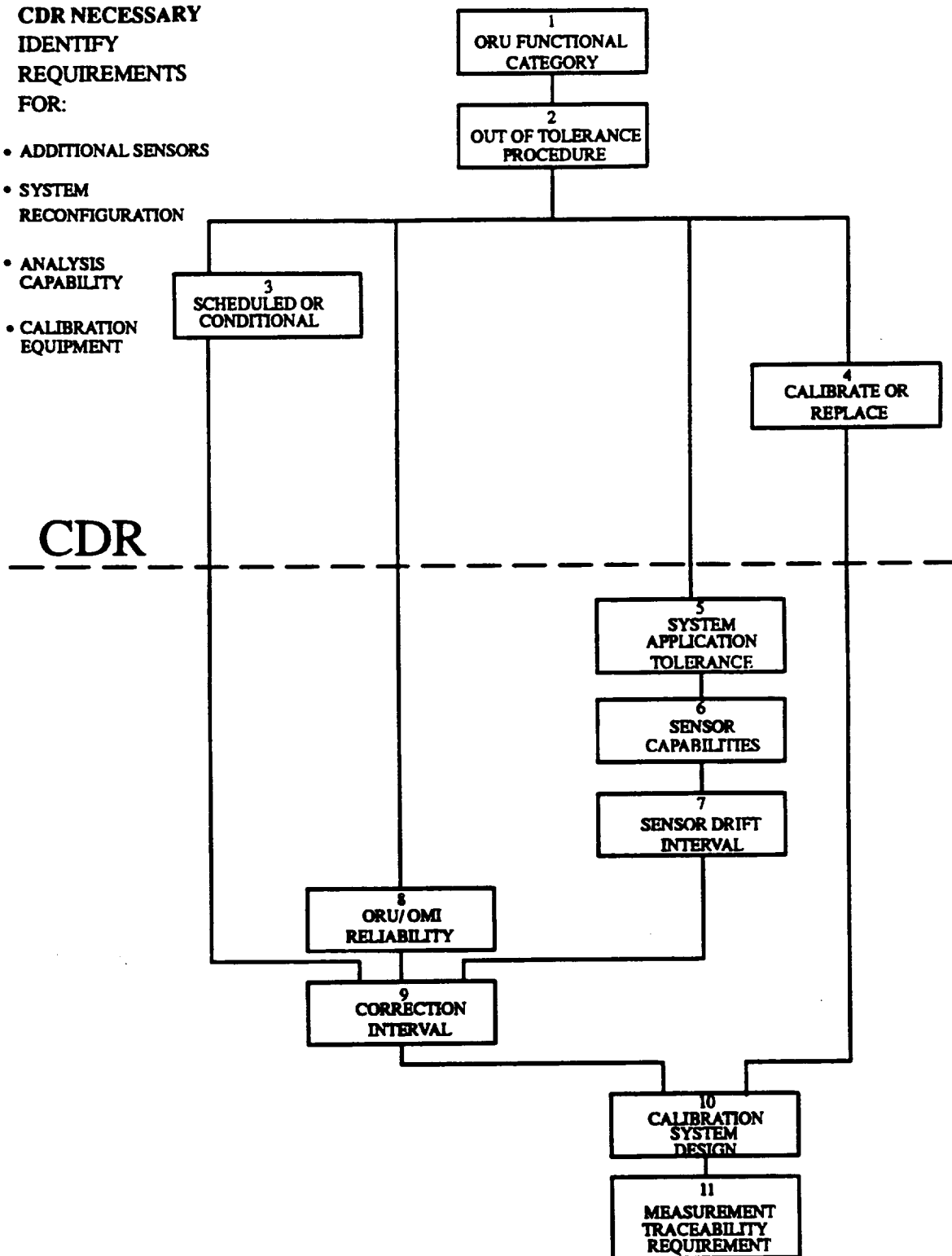
**B.2.3 Method Diagram**

A method diagram, Figure B-9, has been prepared to relate the interdependence of the steps of the metrology process. The dashed line indicates the items that are CDR necessary. The first four steps of the process will reveal deficiencies in the design that require resolution before CDR. They are: (1) the need for additional sensors to be able to determine when a prime sensor is out of tolerance, (2) a required system reconfiguration to make that determination, (3) additional analytical capability requirements to accomplish the determination, or (4) the requirement to have on-board calibration equipment. The remaining steps (5-11) are required to define the spares provisioning, crew training requirements, crew time requirements, storage requirements, and resupply/ return requirements. This effort will validate the design at CDR and provide the rest of the required data after CDR.

Figure B-10 shows the inputs and outputs for the steps of the metrology method.

**CDR NECESSARY  
IDENTIFY  
REQUIREMENTS  
FOR:**

- ADDITIONAL SENSORS
- SYSTEM RECONFIGURATION
- ANALYSIS CAPABILITY
- CALIBRATION EQUIPMENT



**FIGURE B-9 METHOD DIAGRAM**

	INPUT	OUTPUT
1	ORU B1 SPECIFICATIONS OR OTHER SYSTEM SPECIFICATIONS	ORU FUNCTIONAL CATEGORY
2	SENSOR TYPE (VERNIER OR DISCRETE) EMBEDDED PROCESSOR, ORU CATEGORY, FMEA	DESIGN OK OR DESIGN CHANGE REQUIRED
3	MAINTAINABILITY ALLOCATIONS, PERDICTIONS & ANALYSES REPORT, APPENDIX G (D683-10483-1)	SCHEDULED OR CONDITIONAL
4	TRADE OFF PARAMETERS • CALIBRATION EQUIPMENT • CREW TRAINING • CREW TIME • SPARES • CREW TRAINING • CREW TIME	CALIBRATION LIST
5	SYSTEM APPLICATION INFORMATION	SYSTEM APPLICATION TOLERANCE REQUIREMENT
6	SENSOR SURVEY PACKAGE	PARAMETER: RANGE UNCERTAINTY CONFIDENCE LEVEL
7	SYSTEM DESCRIPTION/ SCHEMATIC, SENSOR DRIFT RATE SYSTEM APPLICATION TOLERANCE REQUIREMENT, SENSOR PARAMETERS, DESIRED MEASUREMENT RELIABILITY	ALLOWABLE SENSOR TOLERANCE SENSOR DRIFT INTERVAL
8	COMPONENT DATA	SENSOR MTBF
9	RELIABILITY INFORMATION, B1 SPECIFICATIONS SENSOR DRIFT INTERVAL, ORU/OMI MTBF	CORRECTION INTERVAL
10	CALIBRATION LIST	CALIBRATION SYSTEM DESIGN
11	CALIBRATION DESIGN	TRACEABILITY DIAGRAM

FIGURE B-10 INPUT AND OUTPUT TO THE STEPS OF THE METROLOGY METHOD